Human Factors – occupational safety

A REPORT TO THE LABOUR SAFETY COUNCIL OF ONTARIO

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a report to the Labour Safety Council
of Ontario

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Second Printing, 1973

Ontario

Ontario Ministry of Labour

Hon. Fern Guindon
Minister

R.D. Johnston
Deputy Minister

As a result of the restructuring of my Ministry, as part of the over-all reorganization of the Provincial Government in 1972, the Ministry of Labour is now, in the field of safety, able to give its full attention to occupational safety.

At the Ministry of Labour we have, for some time, conducted a very good program to improve safety at the work place and to prevent on-the-job accidents--by legislation and inspection, carried out by the Industrial Safety Branch and the Construction Safety Branch, as well as through education and research projects.

But obviously, enforcement alone is not the answer, because accidents continue to happen--every minute of every day in every part of the Province.

Every year, Ontario loses more production time through on-the-job accidents than in strikes and lock-outs. Therefore I and my staff are continually seeking fresh approaches that will promote safer work habits and working environment.

This book is an attempt to evaluate those factors that may have a bearing on developing new ways to limit industrial accidents and deaths.

We know that despite all the efforts of management and labour and government, regretfully injuries and fatalities will continue to occur. But nevertheless all of us must strive to develop safer working environment and safer working skills because, if only one accident is prevented, if only one life is saved, then all the time and effort and resources will not have been in vain.

Hon. Fern Guindon
Minister of Labour

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Abstract

The organized safety movement and some assumptions on which it is based are examined.

Criteria for measurement of success or failure are reviewed and an attempt is made to show how these criteria must be considered to be dependent upon one another rather than as separate entities.

The prevention or avoidance of accidents is shown as a complex interaction of forces rather than the simple elimination of "unsafe acts" and "unsafe conditions".

Questions are raised as to the validity of generally accepted practices in the safety movement and stress is placed on the need for greater involvement of Human Factors Engineers and Behavioural scientists.

Preface

From the beginning of time man has found it necessary to survive in a hostile environment. Some of the dangers he can cope with himself, whereas others require external assistance. This assistance may take the form of a dog to awaken him when danger threatens and to help fight the intruder but may be either more complex or more simple. In any case he recognizes that he sometimes needs help and seeks ways of insuring its presence in the time of need. In exchange for such protection he abdicates some of his freedom and, as in the case of the feudal lords, sometimes finds that his desire for protection has merely substituted one danger for another.

The industrial revolution brought with it hazardous machinery and problems which the employee could not solve himself. This situation spawned not only the organized labour movement but a wide variety of organizations devoted to protect the worker from the hazards of his employment.

It is the writer's hope that questions raised in this paper will help encourage the development of more objective research to ensure that the safety movement remains the servant of mankind and does not become the master.

CHAPTER I

INTRODUCTION

AND

STATEMENT OF THE PROBLEM

Introduction

The reader may ask why the writer has selected occupational safety as the basis for this paper when statistics indicate that less than 10% of fatal accidents are attributable to occupational causes, 40% to traffic and the remaining 50% to other facets of life. The answer is as obvious as the question when one realizes that the occupational environment is most easily measured and controlled and occupational safety programs have been active in one form or another in Ontario for almost 90 years. Although early efforts concentrated mainly on removal of enivronmental hazards or technical factors, it is becoming increasingly evident that Human Factors play an important role. "Human Factors Engineering" or "Human Engineering" is the art of adjusting a person's environment to facilitate the most effective and efficient use of his senses and abilities in achieving his goals. It is engineering in the truest sense, since it considers the interaction of the technical and human components of a man-machine system, rather than treating them as separate entities. It utilizes engineering principles to make practical use of psychophysical, medical, and other non-engineering research findings. This study has been prompted by a growing awareness that a purely mechanical approach to safety is far from adequate. This is not to indicate that engineering (in the mechanical sense) has not played an important role, but too often human factors have been ignored to such an extent that the result is either inadequate or detrimental. The purely mechanical approach stems more from the thinking of a technician than from a professional and it is the intention of this paper to provide a platform upon which a realistic accident prevention program can be based. Before we can submit a design utilizing adequate safety factors we must first understand the problem with which we are faced. Engineering deals in probabilities rather than certainties and it is necessary to recognize that our goal in accident prevention is not to eliminate all accidents, but to design a system that loads the dice in favour of safety. In so doing we must be sure that the cost does not outweigh the benefits to be gained. As indicated by Broadbent (4), "The proper road for progress is to set up theories which are not at first detailed, although they must be capable of disproof. As research advances the theory will become continually more detailed". Government and quasi-government programs designed to reduce occupational injuries through education and enforcement now exceed $7,000,000 annually in Ontario alone. This does not include the cost of each company's safety program, which runs in total to many millions more. To say that safety programs save money is a little hollow if we have no way of measuring results. In fact, existing programs may be detrimental if we can believe figures which show Ontario with a higher occupational fatality rate than some neighboring states which have a lower per capita expenditure on such programs. Occupational safety agencies have operated in Ontario since as early as 1884 and in England since 1833 (or earlier). In spite of this long history, the behavioral sciences and human engineering have been virtually ignored and the prime effort has centred around the removal of dangerous conditions and training people in the art of removing or alleviating conditions which are considered unsafe.

In arriving at the observations and conclusions advanced in this paper, I studied many texts, speeches and other literature in the field of safety, physiology and the behavioral sciences; discussed the problems with persons in all phases of accident prevention (Engineering, Education, Enforcement and Research) and visited industrial establishments including a comprehensive study of one factory and a comparison of punch press accidents in Ontario occurring over a two month period. Some of these studies are reported in the text. There appears no doubt that any study of safety cannot be confined to engineering but must involve many disciplines if it is to stand any chance of success.

Statement of the Problem

It is generally accepted that in a free enterprise society industry must operate at a profit to survive. Assuming that humanitarianism takes second place to the profit motive, it would appear reasonable to expect that methods of measuring the value of accident prevention programs have become routine. A search of the literature and personal discussions with engineers, psychologists and accident prevention experts quickly shattered this belief. It appears that comparisons are made by utilizing "frequency" and "severity" and by attributing causality to unsafe conditions or unsafe acts. Direct costs are assumed to be 1/4 of indirect costs but in reality the relationship may vary from zero to infinity. If the 1 to 4 ratio were valid for all accidents it could indicate an annual accident cost of over $600 for every man, woman and child in Ontario. Studies that have tended to validate this ratio have not fully considered the learning, and resulting improved ability to avoid future accidents which is associated with near misses and minor accidents. Although considerable information is collected from investigation of accidents that have occurred, most of it finds its way to inactive files. Where used, it provides only a measure of comparison of past events and points an arrow in the general direction of a problem. It may indicate that a problem exists but it provides no indication of the cause or remedy. Attempts to use such information to predict the future have been rare and usually unsuccessful. The possibility that all accidents are the result of "unsafe acts" or "unsafe conditions" (sometimes referred to as "human factors" and "technical factors") led up a blind alley since unsafe conditions are usually the result of unsafe acts and the point of view of the reporter determined whether the accident was attributed to an unsafe act, unsafe condition, or both. For example, a person involved in an automobile accident on slippery roads may blame the roads (unsafe condition); a non-driver would say that it was unsafe to drive and the person, in driving, performs an unsafe act; and a person experienced in driving on slippery roads, who was not involved in the accident, would blame the incompetence of the driver (unsafe act). The proponents of the unsafe act-unsafe condition concept will admit that what is unsafe for one

(4) This notation refers to the reference to be found at the end of this paper.

person may be safe for another. Here lies a clue to the possibility of recognizing the human factor as a prime component of accident prevention or avoidance.

The use of "frequency" and "severity" in assessing the merits of a program is recognized but this provides only a partial answer. When a change in a program is accompanied by a change in the frequency or severity rate we assume a causal relationship and the program is worked to death. Eventually we find cases where the miracle approach does not work and we wonder why. It is likely that the connection in these cases was coincidental rather than causal. Although there may have been an element of the program which was causal in a specific instance, it may have been some factor not recognized by the observer and which was omitted in the later program. The safety experts have, in such cases, been attending to the wrong dimension of a stimulus, just as pigeons in a psychophysical experiment[43] may attend to colour when the critical variable is shape or orientation. In the past we have had no way of telling which elements are causal and which are coincidental, or perhaps detrimental, as evidenced by cases where the application of a supposedly "proven" program is followed by increased frequency or severity.

Whether we are speaking of Unsafe Acts or Unsafe Conditions, or Frequency and Severity rates, there has been no scientific rallying point that can be used to predict results. All we have done in our approach so far is to assess blame and measure results but even the validity of this is open to question. These measurements have been taken with a device having no universally accepted standard measure for comparison and calibration. We have been merely guessing in our approach to the problem and it may be that many of the so-called improvements instituted in the name of safety increase rather than decrease the total accident experience. The following article entitled "Safety Kills" is intended to illustrate this point more clearly.

Safety Kills

To many people SAFETY is a nasty word. It is associated with squares, do gooders, fanatics and emotionalism. On the other hand, those devoted to the cause of safety have difficulty understanding the attitude of the unconverted. Safety becomes a religion and as in all religious sects, it has its literalists, generalists, reformists and solid citizens, but it is the narrow minded bigot who becomes the symbol of the movement in the public mind.

One of the sad things about safety is that, like the Ten Commandments, it is associated with a series of "don'ts". Negative thinking of this nature automatically evokes the response "why? " It is not too difficult to find moral answers to such questions in the biblical sense but when we apply the same question to safety we find ourselves on shaky ground. We not only ask "why", we want to know —

Who says it is unsafe?
Where did he get his information?
Why does he think it is unsafe for me?
What will happen if I ignore the rule?
When should the rule apply and when should it be waived?
How do I achieve my goal in another way to obtain equivalent satisfaction from the task and the reward?

How often have you been able to get a rational answer to such questions? In my experience, attempts to answer such questions merely evoke more questions. After several attempts at answers, the safety advocate frequently resorts to such defences as "I don't make the law, I just enforce it" or "You are living on borrowed time", or some other feeble argument having no regard to the individual's goals or his ability to cope with his environment.

The tendency is to assume that modern man is a weakling who is unable to protect himself and must therefore be protecte by the safety experts. Hogwash! Many so called safety experts are so busy trying to protect themselves and others from imaginary ills that they completely overlook the fact that the human being is a living organism requiring exposure to stress and new experience to survive and grow. Removal of a person's ability to interact with his environment exposes him to deterioration and death.

This leads us to the title of this paper "Safety Kills". The classic approach to safety is to remove so called "unsafe acts" and "unsafe conditions". In effect it removes experiences and in so doing removes a person's ability to learn to cope with his environment and in the final sense removes his ability to live. Yes, my friends, safety kills, not only in subtle ways such as reducing initiative, freedom and satisfaction, but in more direct ways. Let us look at some safety rules that have caused death.

Stay with the Boat

A sailboat capsized in cold water and the life jackets began to drift away from the boat. One man said he would retrieve them but the other reminded him the *safe* thing was to stay with the boat. As reported by a survivor, both men succumbed to the cold water and drowned half an hour later within minutes of rescue. They died as a result of following the safety rule.

You may argue that they should have been wearing their life jackets at all times. Have you ever worn a bulky D.O.T. approved life jacket while sailing, or tried to right a boat while wearing one? My experience is that I would be more likely to capsize if I was wearing one and I would have more difficulty freeing myself if I was trapped under the sail or in some other awkward position. This danger could be reduced by wearing a smaller jacket which would assist buoyancy but would not prevent freedom of movement. Such jackets are available but are not approved because we assume we are trying to protect only the non-swimmer who is unconscious.

There appears reason to believe that regulations for life jackets, although well intended, may have caused more deaths than they have prevented. What good is a life jacket in the front of a boat to a non-swimmer when he is thrown overboard? Was he trapped by a safety rule that requires jackets to be present but not necessarily worn? I don't have the answers to these questions but I remember being criticized by a lecturer on safety prior to 1960 when, after listening to a spiel on the importance of life jackets and how to wear them, I remarked that I always placed them on my children in reverse because this was the only safe way. He was following the rules whereas I had tested them and found that the jackets then available forced children onto their faces unless worn backwards. How many children have died because their parents relaxed their watch since they were wearing life jackets. Again, I don't know the answer and it is unlikely this could be screened from the statistics since those recording the statistics were not looking for this possibility. They may have reported whether a jacket was worn but who would suggest that *it* was the cause.

This leads us to the question of superstition. Much of our safety rules are pure superstitious gobbledegook and any relationship to fact is buried in antiquity. Let us look at back injuries as an example.

When man commenced his move from country to city his daily exposure to exercise was altered. As this situation accelerated, size and frequency of the loads he was required to lift diminished. His back became weaker through lack of exercise. Medical men began to be concerned about back strains. Safety experts compared the back to a crane and recognized the boom is subject to greater compression loads when horizontal than when vertical. This led to the assumption that keeping the back vertical was a good idea. When someone injured his back it was found that he had been bending over at the time. The temporal association of events tended to place the cause as the person's failure to follow prescribed lifting procedures. Apparently no one recognized that lifting a canoe onto one's shoulders while keeping knees bent and back straight is dangerous if not impossible, or that a person would need to have excessively long arms to reach the floor with his back vertical while retaining a knee angle that would permit lifting more than a package of marshmallows. The knees bent, back straight supersititon, however, has persisted like the black cat and rabbit's foot and may have done an excellent job of creating backs that are strained when the adherent to this principle bends over to brush his teeth after a hard day sitting in a comfortable chair at the office.

The prescribed method is useful in some positions but it may be causing more injuries than it prevents, not only from the physical dangers but through the psychological effect on a person who feels guilty when lifting in a position which is safest for him but which is different than he was taught.

Hand Signals for Bicycles

Another frightening safety rule is for bicycle riders to use hand signals. We assume that since we have classed a bicycle as a vehicle that what is safe for an automobile is also safe for such an unstable two wheeled vehicle. We tell our children to keep both hands on the handlebars and then tell them to remove one hand to signal a turn. This reduces his control, makes it difficult to turn to see if a vehicle is coming and in general increases the cyclist's accident exposure. Recently I had the frightening experience of watching some wolf cubs attempt to pass their cycling test. I was assigned to the intersection of Brookbanks and Parkwoods Village Drive to report those who followed the rules and those who failed. As I anticipated, several of the boys who attempted to cross the intersection in the prescribed manner narrowly missed being struck by cars. I was thankful I had reminded my son before the test that if he followed the prescribed rules I would fail him. Of course I had no choice but to pass those who followed the rules and I was pleased to see that after they passed the test those who had narrowly missed death or injury following the rules reverted to more sensible cycling techniques. This takes me back to my early teens when I was an ardent cyclist.

My parents had instilled in me the belief that bicycles were incompatible with automobiles and trucks. This did not condemn cycling but emphasized that I should keep to the right and where possible get off the road when a car was approaching from behind. I had practiced this successfully since I had become the proud owner of a second-hand bicycle at the venerable age of 6½. At 14 I was reasonably competent and was able to control the bicycle quite successfully. I recognized my incompatibility with the automobiles of the day but was now confronted with safety people telling me a bicycle is a vehicle I must ride on the road rather than the paths of High Park and I should signal for turns. This didn't make sense but I thought I would try, after all they should know. Thank God I didn't kill myself before reverting to my old patterns.

While trying to adjust to the rules I was proceeding east on Bloor Street and wanted to turn north on Keele. My normal procedure would have been to stay to the right until reaching the intersection and then cross with the light at a speed which would not unduly endanger pedestrians attempting a similar task. Under the circumstances this would have been the safest procedure *but* it must be remembered that I was now trying to follow the rules. I was proceeding down a hill with no traffic overtaking me so I moved carefully to the centre of the road. Oh! Ho! you will say, you didn't signal. True, I was fulfilling only part of the rule but I had not been convinced ,that signalling was safe and this is what saved my life a few moments later. I was now coming up behind a streetcar which had just started to move forward after discharging and loading passengers so I was braking slowly but my view of the signal lights was blocked. Apparently the light turned to caution. The streetcar stopped suddenly and I was now in a position whereby I could not stop in time and could not turn back since the tracks would have thrown me out of control. To make matters worse a westbound streetcar had just cleared the intersection so my point of impact with the eastbound car would coincide with the two vehicles being side by side. My only chance of survival was to run the devil's strip between the two streetcars with one stopped and the other coming towards me. I did it without a scratch and shook for the rest of the day. I don't know what the conductor of the westbound streetcar was thinking but he certainly looked shaken. I hate to think of the outcome if I had been signalling at the time. I have ignored the bicycle signalling rule ever since and am convinced that such rules need a drastic overhaul.

I have had similar experiences in driving and other activities but I believe enough has been said on this point for now. Let it suffice to say that although "care", "courtesy" and "common sense" form a nice sounding safety creed, if we want to survive we might do well to concentrate more on "competence", "control" and "compatibility" using the other terms as moral guides to assist in understanding why competence, control and compatability are necessary.

CHAPTER II

HISTORY OF OCCUPATIONAL SAFETY

Early History

Adam's encounter with a serpent in the Garden of Eden may be cited as the first written reference to occupational safety. He had been assigned the task of gardener under God's direction. He had been appraised of his duties and warned of dangers which he must avoid, the most serious being the consumption of the fruit of the tree of knowledge. Under temptation from the serpent he tasted the fruit in the apparent belief that his employer's advice was selfish rather than humanitarian.

Our interpretation of the Bible and its origin makes no difference to the fact that stories of this nature have a moral as applicable today as when the phrases were composed. There appears to be a parallel between this story and the modern concept that "safety is Management's responsibility". Are we assuming that Management knows all the answers and employees are as naive as Adam? Would we have better success if we recognized that today's workers have a better education than the managers of 40 years ago? Such possibilities cannot be ignored.

Taking chances and receiving appropriate reward or punishment appears to be a normal situation for members of the human race. Man has, after all, been acting in this way since his creation and it is unlikely that we will change his nature merely by altering his environment. Perhaps a recognition of this would permit us to design systems that will provide the necessary challenge to maintain ability and alertness without undue danger.[5] It may be necessary to introduce minor dangers to maintain a person's ability to cope with and prevent the occurence of more serious dangers.

The coming of the industrial revolution is considered as a time when great hazards were created for the working man, but history tells us that there were more traffic fatalities in London (England) in 1867 than in 1967. Is it possible that the increased production of the industrial revolution was accompanied by a decrease in accidents per unit of production or that our improved accident experience since 1900 has been primarily due to the replacement of the horse by mechanical devices as a source of power and transportation. It is noted that we still speak of frequency and severity in terms of man hours or man days instead of goods produced or services rendered. Would we have had a better accident experience if we had been able to achieve today's production utilizing animal horsepower as opposed to machine horsepower? I doubt it! Here again is a concept we might question. Traffic experience would indicate that machines are more easily controlled than horses and this is evidenced by a lower incidence of accidents per passenger mile. This principle appears to extend to air travel if statistics can be believed but, just as an automobile crash is more spectacular than a person being kicked by a horse, an airplane crash when it occurs is of a nature that draws more attention than an automobile crash. In any case, human factors are involved that affect the results in a positive or negative way.

Whether the focus on injuries associated with the industrial revolution was due to a real increase per unit of production, an increase in numbers associated with a decrease per unit of production, or merely a localization of injuries in buildings and premises where improved accident records could be kept would be difficult to prove. There is no doubt, however, that during the 19th century the problem of industrial accidents began to receive the attention of persons other than the injured workers and their immediate families. Associations dedicated to reducing industrial slaughter and suffering began to spring up and legislators began to pass laws for the protection of workers. Although safety associations (e.g. The Royal Society for the Prevention of Accidents) and the administration of laws such as England's "Factories Act" (1833) and "The Ontario Factories Act" (1884) played a part in improving working conditions, they concentrated primarily on technical factors such as machine guarding and tended to give little attention to human factors as a preventive or remedial force. They did, however, consider human factors in the causal sense by referring to "unsafe acts". Safety programs have sometimes been based on inadequate data but even the more sensible requirements have met with opposition of varying strength and validity; for example, the "National Association of Factory Occupiers" was formed in Manchester, England, in 1855 with the express purpose of opposing the Factory Inspectors' requirements concerning the guarding of shafting. Dickens in his "Household Words" referred to this body as "The Association for Mangling of Operatives". When occupational safety legislation was first introduced and until the 1930's there was no question that working conditions were unsafe by today's standards. A glance at most photographs of a factory operation of this period will indicate the presence of such a large number of hazards that one might wonder how anyone survived.

During the second decade of the 20th century the introduction of Workmen's Compensation legislation began to focus attention on the benefits that would come to industry if, as a group, they could reduce their accidents and associated compensation payments. This spurred the formation of industry groups dedicated to accident prevention, some receiving official recognition and support through their Workmen's Compensation Board. In general, these associations have concentrated on safety education leaving enforcement to governmental bodies. Other local and national safety associations have grown up where a need has been recognized. These include such bodies as the National Safety Council (U.S.), National Safety League (Canada), Canadian Highway Safety Council, Ontario Safety League, Canadian Industrial Safety Association and many others too numerous to mention here. We will conclude this brief history by noting that the National Safety Council reported[31] an occupational injury frequency of 31.87 (per million man hours) for their participating firms in 1926, dropping to 15.12 in 1931 and 6.91 in 1966 (with normal fluctuations). Since removal of so called "unsafe conditions" was still the vogue in the 1920's the 50% reduction in accident frequency in a 4 year period appears inconsistent with the belief that not more than 20% of accidents are attributable to unsafe conditions. Although North American officialdom has been involved for nearly 100 years in programs devoted to prevention of occupational injuries and an enormous amount of information has been collected it appears that little progress has been made in

finding the true reasons why accidents occur. If this could be done we could develop a model to predict the results of a proposed improvement in a program. This is the challenge for the future, but let us first take a closer look at the situation today as developed by a century of trial and error.

The Situation Today

Safety permeates every facet of life and most, if not all, people have opinions on the subject. Occupational safety is no exception and the importance of protecting workers from unnecessary hazards in their employment through the enforcement of laws has (as mentioned earlier) been recognized since the middle of the 19th century.[17] The effectiveness of this approach in drawing attention to hazards cannot be ignored and was possibly one of the factors which motivated the formation of associations dedicated to promoting knowledge of safe practices. These educationally oriented safety associations began to spring up in the early part of the 20th century and have shown continued growth in numbers and services since that time. It is often said that safety consists of the three "E's" which are "Education", "Engineering" and "Enforcement". For some unexplained reason the importance of research as a foundation for each of the three E's seems to have received little recognition in the occupational safety field. It is the only source from which reliable improvements can spring, but unfortunately, when such research has been undertaken it has been approached on a sporadic and piecemeal basis, answering few, if any, questions. It does, however, raise sufficient questions to stimulate a desire for more scientific and statistically reliable research to develop concepts capable of placing safety programs on a firm foundation. I accept the fact that considerable excellent safety research is being undertaken, particularly in the United States, but it is primarily oriented to military and traffic applications. In spite of this, an examination of research reports emanating from these agencies indicates that some of the principles being developed are applicable to occupational safety and their work can form a basis for realistic occupational safety research. The uncontrolled (decision by crisis) growth of accident prevention programs throughout the western world in the past century has followed similar patterns to that shown in Ontario In the resulting patchwork, co-ordination is lacking and research, if existing, must be conducted on a piecemeal basis by or under the auspices of each agency.

We have created agencies to educate and enforce but the basis of their recommendations is questionable. We attack the problem with job safety analysis, fault tree analysis,[26] frequency and severity as related to millions of manhours, we attempt to break down the accident into unsafe conditions or acts and more precisely by cause and agency, we analyze events associated with an accident or series of accidents in an attempt to find causality and develop improvements but we often fail due in part to our lack of understanding of the underlying causes and the interaction of all forces and systems in the total environment.

We tend to look only at accidents which have occurred and ignore those which were successfully avoided and in so doing may relocate rather than remove the danger. One might ask whether street lighting reduces accidents or merely relocates them to adjacent streets due to a reduction in dark adaptation caused by the difference in illumination. Most of our accident prevention work tends to ignore such possibilities.

It appears unlikely that useful occupational safety research will be conducted in Canada until government and industry recognize the weaknesses existing in the present programs and pool their efforts towards finding the true causes of accidents and their remedy. Without comprehensive research, it is impossible to determine which, if any, of our efforts towards accident prevention are useful. We have developed methods to measure frequency and severity of accidents and have attempted to infer causality by speaking of unsafe acts and unsafe conditions, but this approach has no predictive value. It is the writer's belief that if we are to succeed in an effective safety program we must rely more heavily on interdisciplinary research and ensure that educators, law enforcement personnel, industry, and the public are supplied with information which is supported by reliable scientific verification.

One of the purposes of this paper is to point out the lack of "human engineering" (which combines engineering, psychology, physiology, and other disciplines) in most safety programs existing today and to show not only the need for such an approach but how human engineering can help place safety on a more scientific basis. Occupational safety was selected for the study since it is a field where some control can be exercised over the environment. Since considerable attention and effort has focussed on ways to reduce monetary and human loss in industry, it was assumed that there could be found in the industrial safety literature, information that would explain accident prevention programs and concepts that had been tested and could be used for predictions with some statistical validity. I soon ran into problems. Existing literature left me with more questions than answers. To approach the problem of Human Factors in Occupational Safety I found it necessary to set aside the classic texts, become familiar with concepts of related disciplines and do some basic thinking. In so doing, a pattern began to form, and I was able to return to the classic approaches and fit them into their appropriate place in the finished picture.

The Need for a New Approach

In briefly reviewing the history of accident prevention and the level to which we have progressed, we have pointed up some problems. We have seen that tools have been developed to help us measure whether the situation is improving or deteriorating. These tools are subject to many problems including the fact that they are not universally accepted, and where used are often modified to such an extent that comparisons are impossible. Existing statistics relate to the technical and human factors of accidents which have occurred, ignoring those which have been successfully avoided, prevented or minimized by human action and do not attempt to relate the results to units of production. Even where the human factor is considered in accidents that have occurred, it is usually passed off as an "unsafe act" which is a relative term and (as will be discussed later) has no real meaning.

There appears to be a genuine need to develop an approach

to accident prevention which is measurable and lends itself to predictions for the future. Although a new approach is necessary it would facilitate its acceptance if existing concepts could be, where possible, integrated into the model. By comparison, it did no harm and perhaps speeded the acceptance of the automobile to locate the engine where the horses used to be. Although such principles are often criticized, they are necessary considerations in human engineering for safety.

Let us now look at some of the concepts upon which safety is or could be built. Although safety is a basic necessity that follows us from cradle to grave, most of us are somewhat fuzzy in defining what it is. Safety permeates the entire hierarchy of our biological, physiological and sociological needs. Although some scholars have shown it in a specific location on the list of needs, it can be argued that each need or drive is dedicated (at least in part) to the safety of the organism or what the organism believes will be an improved safety or comfort state. If we have a homeostatic tendency to seek a state of equilibrium or comfort it appears logical to assume that each of our actions is intended to bring us closer to such a state. The fact that our action may be faulty or misdirected is immaterial to the concept. Whether we are stationary, mobile, asleep, awake, working, playing, or involved in any other activity or lack thereof, we are subject to stresses which we endeavour to remove. In attempting to remove these stresses we create others along with a chance that the new state may be less secure than the one we abandoned. Basic psychology uses such relationships as B = HE, i.e. Behaviour is a function of Heredity and Environment. If such a relationship exists (and there is considerable evidence that it does) then we can say that heredity and environment play a part in whether a person will be involved in an accident. It would, therefore, be unwise at this time to make a broad statement as to whether exposure to past hazards bears a direct or inverse relationship to a person's safe behaviour in future circumstances. Whether experience is beneficial or detrimental appears to vary with the experience and the individual. Similarly, human abilities and physical dimensions vary so greatly that designing for the average populace or even for 95% of the population automatically excludes some people.[6] If we design a device under such rules we may be increasing the probable accident exposure to persons falling outside of the design limits. This may be remedied by selection of personnel who fall within the design limits or by increasing the design limits to encompass 100% of the population. Safety permeates the animate and inanimate, but the organized safety movement has tended to ignore the animate and concentrate on inanimate or technical aspects that are more easily measured. Until recently, attempts made to extend safety programs to the animate have met with failure, or at best, sporadic success. Where successes have occurred, attempts to utilize the same approach elsewhere have failed.

In studying accident prevention literature, it was noted that the authors invariably come to the conclusion that accident causes are either "unsafe acts" or "unsafe conditions". Speeches, training courses and entire programs have been built around the belief that reduction in unsafe acts and unsafe conditions will reduce the frequency and severity of accidents. No one, however, seems to have stopped to define an unsafe act or unsafe condition adequately, and where they have attempted to do so they have either ignored or not attempted to answer the perplexing fact that removal of hazards is not always accompanied by a reduction in accidents. The interaction or spill-over of improvement in accident prevention (either negative or positive) to adjacent areas and the varying abilities of individuals to cope with their environment has, in general, not been considered.

If we attempt to define "unsafe condition" we find ourselves with "a condition which may result in injury to a person". This condition is, to some degree, created by human action or inaction which leaves us with the situation that an unsafe condition is usually the result of an unsafe act. If no one is aware of the condition it cannot be removed and we can only define it as an unsafe condition after the injury has occurred. On the other hand, if a person is aware of the danger and does not take corrective action, any injury must be the result of inaction or inappropriate action by the person who was aware of the danger. The injury, therefore, is the result of an unsafe act. An unsafe condition then becomes a condition which is either the result of an unsafe act or which is unknown until after an injury results, making unsafe acts the prime object of our concern. An "unsafe act" is easily defined as "action or inaction which may result in injury". This, again, is not much use since an act can only be considered unsafe in the light of the individual's ability to cope with his environment. We must, therefore, develop a broader concept than unsafe acts and unsafe conditions.

Although methods have been developed to measure accident experience, the concept of predictability of accidents or planning to prevent accidents intelligently has only recently been considered as practicable through Job Safety Analysis, using the "Fault Tree"[26] and other methods. Being faced with a recognition of weaknesses in existing approaches to accident prevention, I have endeavoured to start from the beginning considering the man-machine, or man-environment interface, from the point of view of the man and his ability to cope with the hazards of his environment.

New phrases and relationships are advanced to explain accident causes, analyses and remedies in a manner that is easily remembered. Criticism of existing practices is not intended to indicate they are wrong, but merely to emphasize their limitations so they can be used effectively within these limitations.

Let us now look at some preliminary work that reinforced the writer's belief that a new approach concentrating more heavily on human factors is necessary.

When first approaching the possibility of looking at safety from the human engineering point of view, I was frequently faced with people having the firm belief that humans are so unpredictable that you cannot expect them to take reasonable precautions. This leads to attempts at doing such a thorough job of removing hazards that a person cannot hurt himself no matter how hard he tries. This could be considered a "padded cell" philosophy of accident prevention. It assumes that people want to hurt themselves and forgets that people may be more effective in preventing accidents than they are in causing them. Conversations indicated that people who believed that others fell into the category requiring a padded cell often were

convinced that they were personally capable of assessing dangers and taking appropriate action.

Safety Survey Questionnaire

The following pages explain an opinion survey that was conducted by the Labour Safety Council of Ontario to determine whether people in various age, experience and occupational groups would place responsibility for safety on themselves or others.

During the latter part of 1966 a safety questionnaire (Fig. 1) was used at exhibitions and conferences to try to determine what people of different age, sex, experience and occupation groups considered as important factors in accident prevention. To the surprise of people with many years experience in the occupational safety field, the majority of people completing the questionnaire placed more emphasis on the individual's ability and responsibility than on external forces such as enforcement, supervision, etc.

In all categories of respondents the employee was considered to be the person who was most important in preventing accidents. Similarly, safe work attitudes were considered to be fostered mainly by "individual sense of responsibility", "provision of safety tools and equipment" and "training and instruction of safe methods and working procedures". Although the sampling covered a broad cross section of the population, the number of persons covered (368) was such that it would be dangerous to attach statistical validity to the results. The consistency of results, however, reinforced our belief that a study of the personal factors or "human factors" warranted further investigation.

The results of 191 questionnaires completed by a sampling of persons visiting the 1966 Canadian National Exhibition is shown in Fig. 2 and Fig. 3. To emphasize the consistency of results, Fig. 2 shows the results as a percentage of the total of persons in the category being considered. For simplicity of comparison, the results are shown in Fig. 3 merely as a rank from 1 to 10 in each category with rank 1 being the highest and rank 10 being the lowest.

Although it appears that the employee is considered most responsible to prevent accidents, the construction of the form could have been a factor in the result. If results for management and supervisors are combined we find that out of 14 categories, employees head the list in eight cases, but are surpassed by the management-supervision total in five cases, and in one case are tied. The remaining difference could be due to the fact that "employees" appears ahead of "Management" and "Supervisors" on the form. It does, however, appear significant that all categories placed the majority of responsibility on internal vs. external factors, i.e. Government, Unions and Education organizations were rarely considered to have a prime role by persons completing the forms.

In the list of fifteen factors that contribute to a safe attitude at work, the first ten were ranked in each category. The most significant result was that three factors received a rank of four or less in every category. These were "personal sense of responsibility", "provision of safety tools and equipment" and "training and instruction of safe methods and working procedures". At the other end of the scale, safety slogans and safety certificates did not appear in the top ten in any category. "Management awareness of safety" and "safety inspections by Government", although receiving some support, in no case were ranked less than four with average ranks of 6 and 6.3 respectively. This again appears to indicate the importance of internal or local factors, with external factors primarily useful as reinforcement or background information.

A Comparison of Factories Having Varying Accident Experience

Although the random survey reinforced the idea that human factors are important in accident prevention, there appeared to be some doubt as to whether the principle is true in industry. This was based on a strong belief in some quarters that "safety is management's responsibility". This phrase, although not intended to deplete individual responsibility, has been interpreted by some to remove all responsibility from the individual worker, and as previously indicated, leads to safety programs based on the idea that you must protect people from themselves. Although there might be some reason to excuse management for such a belief, it would only be valid if the employees were naive and incapable of learning. It is also sad to hear workers' respresentatives using the impassioned plea "Management must protect our boys" when it is these "boys" who, in many cases, either create or eliminate the dangerous situation. Fortunately most employers and workers' representatives with whom I have had contact recognize that accident prevention is a joint responsibility. Since companies have varying accident experience it appeared that a comparison of premises where the accident experience had increased, decreased or remained relatively constant might provide some clues as to the reasons.

The safety records of twenty industrial establishments were analyzed to determine whether there might be some common factors that were coincident with an increase or decrease in accident experience. It was originally intended as a prelude to a study of the relative effectiveness of externally applied education and enforcement on a company's accident experience, but a study of this nature was found to be frought with many difficulties related in part to the divided responsibility for safety enforcement and education in Ontario and has, therefore, been temporarily set aside. The results of the preliminary study have a bearing on this paper since the personal interviews conducted as part of the study appear to be consistent with the opinions gleaned from the safety survey questionnaire. The investigations indicated that companies with a good accident record recognized that the employees had a part to play and that the employer must establish policy, administer it effectively and ensure that the employees were not only provided with safe tools and equipment but were adequately trained in their safe use. There was no significant correlation between an increased frequency of inspection (by the educational or enforcement agency) and a reduction in accidents. On the contrary, it appeared that if any correlation existed it was in the probability that an inspection would be made as a result of an increased accident frequency. Although the accident frequency sometimes showed a decrease after a large number of inspections the lack of correlation was such that the reduction could be merely statistical chance. If the reduction was due to some cause the most likely candidate

FIG. 1

LABOUR SAFETY COUNCIL OF ONTARIO
SAFETY QUESTIONNAIRE

This questionnaire is designed to give you the opportunity of telling us, what in your opinion, are the most important points in a safety program.

We thank you for this assistance in helping us to determine the future of safety in Ontario.

Signed,
D.F. JONES
Executive Director

1. Sex
   - ☐ male
   - ☐ female

2. Age
   - ☐ under 16
   - ☐ 16-25
   - ☐ 25-40
   - ☐ over 40

3. Occupation
   - ☐ management
   - ☐ supervision
   - ☐ non supervisory
   - ☐ self employed
   - ☐ other

4. Total Work Experience
   - ☐ less than one year
   - ☐ 1-10 years
   - ☐ over 10 years

5. Whose responsibility is it to prevent accidents? Check the most important one in your estimation.
   - ☐ educational organizations
   - ☐ employees
   - ☐ government
   - ☐ management
   - ☐ supervisors
   - ☐ unions

6. A number of factors are said to contribute to a "safe" attitude at work — Check the five most important —
   - ☐ close supervision
   - ☐ company safety rules
   - ☐ fear of injury
   - ☐ individual sense of responsibility
   - ☐ love of home and family
   - ☐ management awareness of safety
   - ☐ posters — pictures — safety films
   - ☐ Provision of safety tools and equipment
   - ☐ safety certificates — citations — awards
   - ☐ safety inspections by government
   - ☐ safety inspections by employer
   - ☐ safety slogans and creeds
   - ☐ safety talks — speeches — meetings
   - ☐ training and instruction of safe methods and working procedures
   - ☐ warning signals

7. Write any comments or criticisms you have of existing employment-oriented safety legislation, enforcement policies or educational programs.

NUMBER OF REPLIES AS A % OF GROUP UNDER CONSIDERATION

FIG. 2

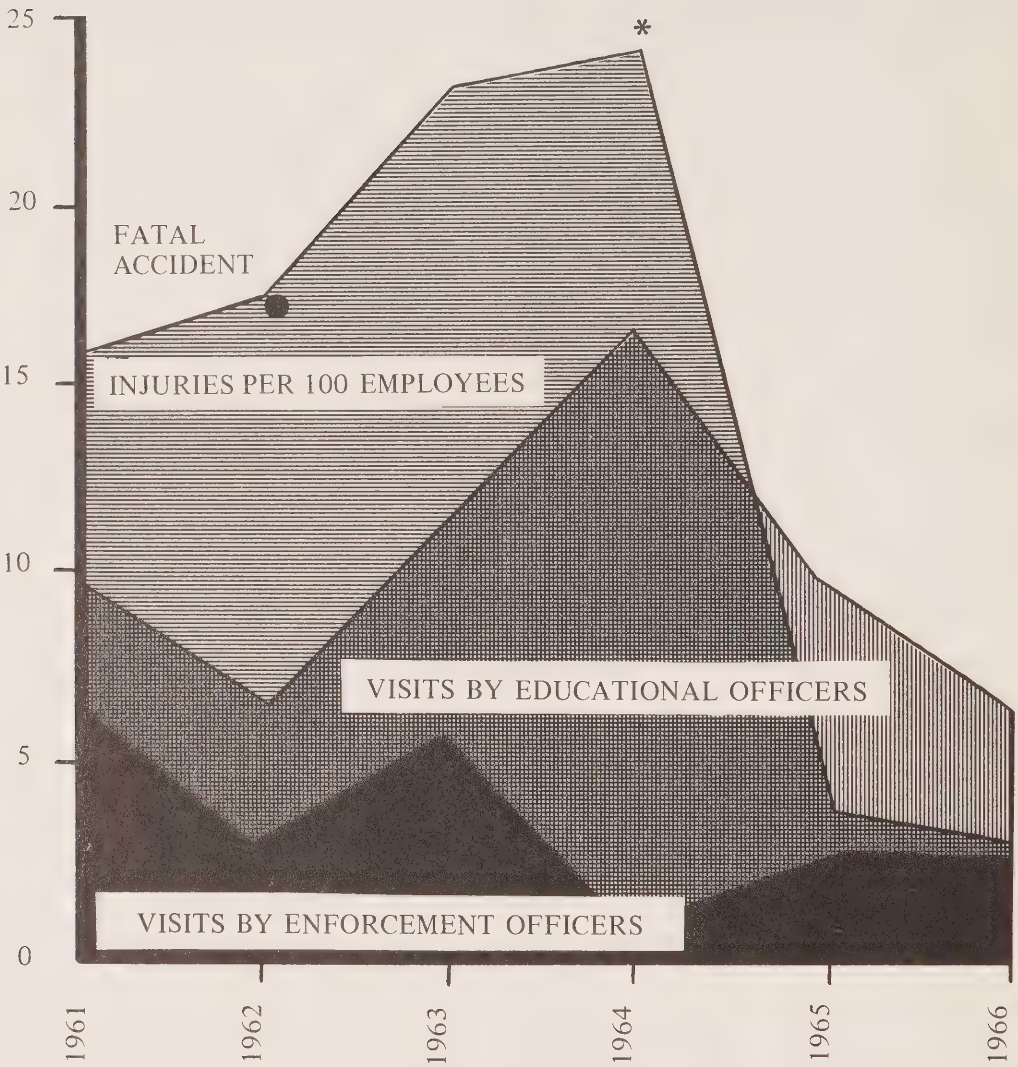
	SEX		AGE				OCCUPATION					YEARS OF EXPERIENCE		
	M	F	under 16	16 – 25	25 – 40	over 40	management	supervision	non supervision	self employed	other	less than one year	1 – 10 yrs.	over 10 yrs.
Education Organizations	7	7	6	6	5	11	0	2	5	19	8	6	2	9
Employees	46	48	49	57	40	33	33	43	53	30	50	44	58	42
Government	8	10	6	13	5	7	7	7	5	13	10	9	12	4
Management	16	26	13	10	24	27	20	18	16	25	18	13	15	20
Supervisors	19	7	13	8	24	22	40	25	16	13	10	13	9	25
Unions	3	3	13	6	0	0	–	5	3	0	4	15	2	0
No Answer	1	0	0	0	2	0	–	–	2	0	0	0	2	0
Close Supervision	6	2	5	4	4	9	8	7	5	5	4	5	3	7
Co. Safety Rules	9	8	10	11	7	9	8	9	10	10	9	11	9	9
Fear of Injury	3	2	1	4	2	3	5	2	3	0	3	2	3	2
Individual Resp.	15	18	18	16	15	14	12	14	17	13	17	18	16	15
Love of Home, etc.	3	4	4	3	3	3	0	3	5	2	3	4	2	3
Management Awareness	7	10	8	7	10	6	9	8	7	6	8	8	7	8
Posters, etc.	3	1	4	1	3	3	0	3	4	4	2	2	2	3
Safe Tools, etc.	13	14	13	12	14	13	15	12	15	11	12	14	14	13
Safety Certificates	2	1	1	2	2	0	0	3	0	1	1	1	1	1
Government Inspections	8	7	10	7	8	7	4	8	7	10	8	7	9	7
Employer Safety Inspection	8	8	3	7	7	11	12	6	6	11	8	5	8	8
Slogans	1	0	3	2	1	0	0	2	0	3	1	1	2	0
Talks & Meetings	4	1	3	3	2	4	4	3	2	6	3	2	2	4
Training	14	14	10	13	17	13	16	15	12	13	15	12	15	15
Warning Signals	5	10	7	8	5	5	7	5	7	5	7	8	7	5
Number of Replies	149	42	16	70	58	45	15	40	38	16	82	32	65	80

FIG. 3

	M	F	under 16	16 – 25	25 – 40	over 40	management	supervision	non supervision	self employed	other	less than one year	1 – 10 yrs.	over 10 yrs.
Education Organization	5	4	5.5	5.5	4.5	4	6	6	4.5	3	5	6	6	4
Employees	1	1	1	1	1	1	2	1	1	1	1	1	1	1
Government	4	3	5.5	2	4.5	5	4	4	4.5	4.5	3.5	5	3	5
Management	3	2	3	3	2.5	2	3	3	2.5	2	2	3.5	2	3
Supervisors	2	5	3	4	2.5	3	1	2	2.5	4.5	3.5	3.5	4	2
Unions	6	6	3	5.5	7	6.5	6	5	6	6.5	6	2	6	6.5
No Answer	7	7	7	7	6	6.5	6	7	7	6.5	7	7	6	6.5
Close Supervision	8	10.5	8	9.5	9	5.5	6.5	7	9.5	9.5	8	8.5	9.5	7.5
Co. Safety Rules	4	6.5	4	4	6.5	5.5	6.5	4	4	5.5	3	4	4.5	4
Fear of Injury	–	10.5	–	9.5	–	–	9	–	–	–	10	–	9.5	–
Individual Resp.	1	1	1	1	2	1	3.5	2	1	1.5	1	1	1	1.5
Love of Home, etc.	–	9	9.5	–	10.5	–	–	–	9.5	–	10	10	–	–
Management Awareness	7	4.5	6	7	4	8	5	5.5	6	7.5	5	5.5	7.5	5.5
Posters, etc.	–	–	9.5	–	10.5	–	–	–	10	–	–	–	–	–
Safe Tools, etc.	3	2.5	2	3	3	2.5	2	3	2	3.5	–	2	3	3
Safety Certificates	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Government Inspections	5.5	8	4	7	5	7	10.5	5.5	6	5.5	5	7	4.5	7.5
Employer Safety Inspection	5.5	6.5	–	7	6.5	4	3.5	8	8	3.5	5	8.5	6	5.5
Slogans	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Talks & Meetings	10	–	–	–	–	10	10.5	–	–	7.5	10	–	–	10
Training	2	2.5	4	2	1	2.5	1	1	3	1.5	2	3	2	1.5
Warning Signals	9	4.5	7	5	8	9	8	9	6	9.5	7	5.5	7.5	9
Number of Replies	–	–	–	–	–	–	–	–	–	–	–	–	–	–

appears to be a sudden awareness on the part of management and employees that a problem existed that required a solution. Many factors could contribute to this awareness, including frequency of inspection, severity and frequency of accidents, and increased compensation payments. Although an extensive study would be required to verify or refute the foregoing possibilities, some dramatic cases of accident reduction associated with a change in management attitude were noted. Fig. 4 shows the experience of one such company for the calendar years of 1961 to 1965. The question of awareness of danger contributing to accident reduction was also evidenced in the mining industry where, for the period 1961-1965, an increase in fatalities was accompanied by a decrease in accidents and a decrease in fatalities was accompanied by an increase in accidents (Fig. 5). This industry is closely knit in Ontario and reports of all fatal accidents are circulated among the members. Although the relationship may have been coincidental, the same relationship occurred in over 60% of the years 1940 to 1960 and was also evident in a group of utilities who follow a similar practice of distributing information on accidents that could be of interest to all members.

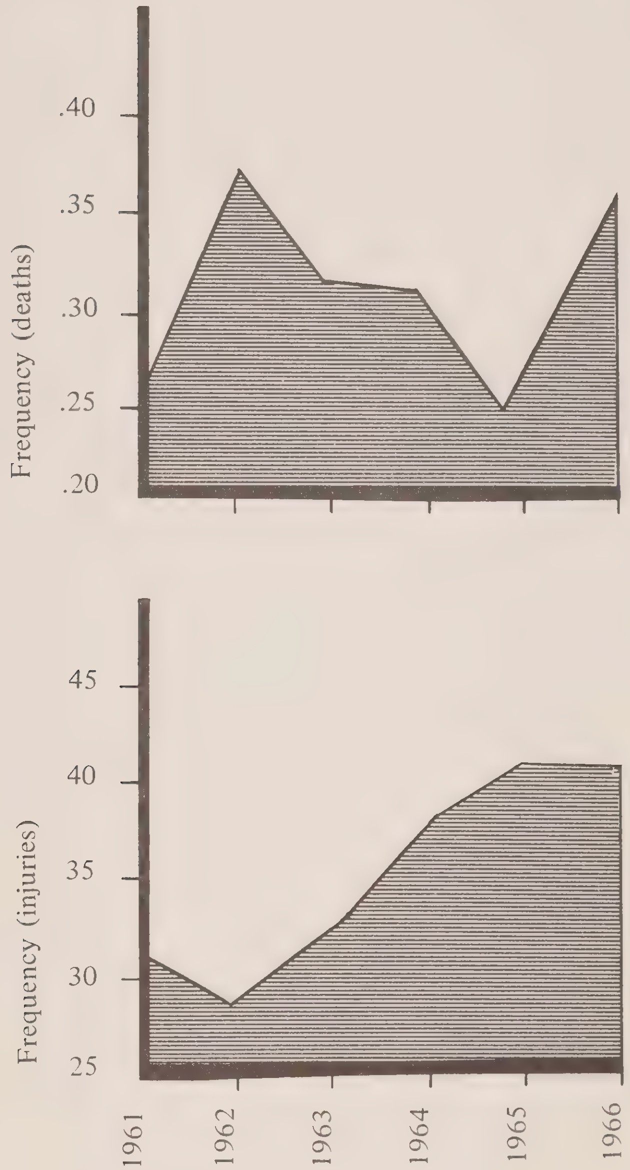
FIG. 4
EXAMPLE OF ACCIDENT REDUCTION ASSOCIATED WITH MANAGEMENT RECOGNITION OF THE PROBLEM



*Oct. 1964 – Management became aware that their grestest single cost was compensation. This was coincident with submission of a report by a consultant from the educational agency, including an accident cost analysis of the company's operations.

Fatal Accidents occurred April 18th, 1961 and Jan. 3rd, 1963.

FIG. 5
MINE ACCIDENTS (ONTARIO)
Courtesy — Mines Accident Prevention Association of Ontario



CHAPTER III

PROPOSALS FOR IMPROVEMENT

FIG. 6

WORDS AND PHRASES USED TO DESCRIBE POSSIBLE HUMAN FACTORS IN ACCIDENT CAUSATION

(A list of suggested causes gleaned from safety research literature).

AGGRESSIVENESS, ANXIETY, ALERTNESS, AGE, ADAPTATION TO WORK, ATTITUDE, ATTENTION, ASSESSMENT OF DANGER, ALCOHOL,

BLOOD PRESSURE, BREATHING RATE, BLOOD ADRENALIN CONCENTRATION, BOREDOM, CO-ORDINATION, CONCENTRATION, CARELESSNESS,

DOMESTIC PROBLEMS, DISTRACTION, DRUGS, DEPRESSION,

EGO, EARLY ENVIRONMENT, EXAGGERATED SELF CONFIDENCE, EXPERIENCE, EMOTIONAL STABILITY, EMOTIONAL MATURITY, ELECTRICAL RESISTANCE OF SKIN,

FEAR OF SUCCESS, FEELING OF SOCIAL INDEPENDENCE, FUNCTIONAL PLASTICITY, FATIGUE,

HEARING, HEIGHT, HEAD SIZE, HOSTILITY, HASTY DECISIONS, HASTY ACTIONS,

INORDINATE AMBITIONS, IMPULSIVENESS, IRRATIONAL ATTITUDE TOWARD PAIN, INDIVIDUAL'S ACCIDENT HISTORY, INTELLIGENCE,

LACK OF DISCERNMENT, LACK OF SENSITIVITY TO OTHERS, LEFTHANDEDNESS, LOCOMOTOR ABILITY, MENTAL PROCESSES IN CONFLICT, MOTORABILITY, MANUAL DEXTERITY,

NEED FOR AFFECTION OR ATTENTION,

OVERCONFIDENCE, OXYGEN CONSUMPTION, OLFACTORY SENSITIVITY, PERCEPTION, PULSE RATE, PSYCHOMOTOR DEFECTS, PERTURBATION,

REVOLT AGAINST PARENTS, REACTION TIME, RESPIRATORY CAPACITY, REASONING POWER,

SKILL, SENSE OF RESPONSIBILITY, SAFETY CONSCIOUSNESS, STAMINA, SOCIAL ACCEPTANCE, SELF DESTRUCTIVE IMPULSE, SOCIAL REJECTION, TRAINING, TACTILE SENSITIVITY, TASTE,

UNCONCIOUS GUILT, UNSAFE ACT, UNSAFE CONDITION, UNINTEGRATED SOCIAL ATTITUDE,

VENGEFUL ATTITUDE, VISUAL ACUITY, VISUAL COLOR DEFECTS, WORK DAY TOO LONG.

Development of a New Approach

To develop a suitable approach to "human factors in occupational safety" we must first define our terms of reference.

The Oxford International Dictionary defines safety as "the state of being safe; exemption from hurt or injury; freedom from danger, sometimes the safety of more than one person". It continues to define specific items such as the "Engineering factory of safety", "safety-bolt" for guns, etc. The Britannica World Language Dictionary says, "the state or condition of freedom from danger or risk", "freedom from injury", "harmlessness". It can be seen from this that safety is a relative thing and whether something is safe or not is in the eye of the beholder. We cannot speak of safety as a measurable quantity unless we first decide the degree of risk or danger that we are prepared to tolerate and the frequency at which we are prepared to receive the harm or punishment associated with failure to succeed in the face of that risk or danger. We must also determine whether we are interested in risk to the machine, product, individual, group, company, municipality, nation, or humanity, since they are not necessarily compatible. This is evidenced in Fig. 5 which appears to show an inverse relationship between the incidence of fatal and non-fatal accidents. Relationships of this nature indicate the possibility that a small number of high loss accidents adequately publicized may be accompanied by such a reduction in lower cost accidents that there is a net gain to the economy. The loss to individual families and the work groups involved in the high loss accidents in these cases, however, is higher than if they had a less severe accident. Conversely, the presence of moderately serious accidents may minimize the possibility of more serious accidents. This is contrary to the belief normally held in accident prevention circles that accidents must be controlled regardless of severity since the consequences are merely a matter of chance, e.g. a minor cut may become infected resulting in possible death. Although principles advanced in this paper may be applicable to all aspects of safety, we are concerned primarily with occupational safety.

What is Occupational Safety?

Occupational safety can have different meanings for different people. To the financier it may be the security of his investment. The factory manager may consider it the cost of accidents (men and machines) per unit of production. To the individual worker, occupational safety is a more personal thing involving his life and that of his friends. If we consider occupational safety to be the safety of men and machines in an environment in which a person works for remuneration we have a foundation on which to build, but we must first define what we mean by "safety". If we define a safe environment as one that prevents or discourages accidents, we must define "accident".

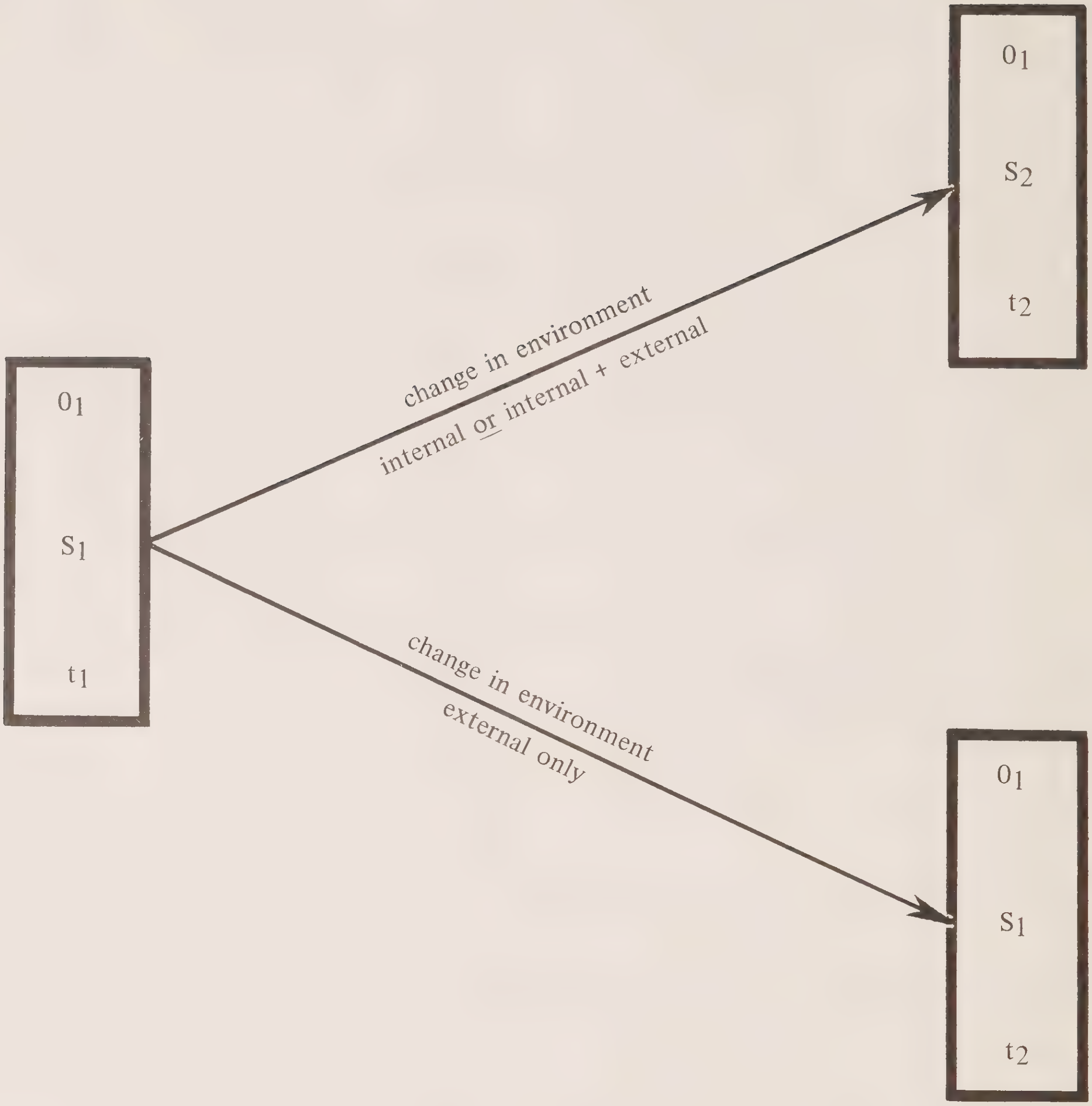
The Oxford International Dictionary says that an accident is "anything that happens", "any unforeseen event or contingency" along with specific references such as an irregularity in the landscape. The Britannica World Language Dictionary defines accident as "anything that happens by chance", "anything occurring unexpectedly, undesignedly, or without known or answerable cause", "a contingency, especially any unpleasant or unfortunate occurrence involving injury, loss, suffering or death". Since industrial safety must relate its success to cost per unit of production, whether the loss is intentional or otherwise, the last definition appears most suitable to our purpose. It avoids any discussion of fault (except insofar as it will assist in finding a remedy). An accident might also be defined as an unforeseen, unplanned or uncontrolled event[17]. In industry we are interested in cost per unit of production, in which case an accident becomes an unforeseen, unplanned or uncontrolled event which results in personal injury or property damage. Such events which do not result in personal injury or property damage, but which could have had such results, are also of interest to industry since they serve as warnings. It is often difficult, however, if not impossible to uncover dangerous events unless personal injury or property damage has, to some extent, occurred.

We have some chance of developing a reasonable model if we restrict our thoughts and comments to the safety of workers since there is some control over their environment. Control of the human components is also possible through employment policies in an industrial operation, albeit to a lesser extent than the environment can be controlled.

The normal method of studying safety in an industrial setting is to study accidents which have occurred. Some people argue that proper foresight will prevent accidents, thereby eliminating the need for hindsight and that the occurrence of an accident automatically indicates that an unsafe condition exists or an unsafe act was committed. Such an argument leads to a sometimes fruitless and inconsistent program to eliminate so called unsafe acts and conditions. It is in many cases sad to realize that although the motive is sincere, the result may be the opposite of what is expected. What is often ignored or improperly assessed in such programs is the "human factors" which include resentment (mind) and muscular co-ordination (physical) (see also Fig. 6). It has long been argued that the elimination of unsafe conditions and unsafe acts will eliminate accidents. Most of those who work diligently to achieve this result recognize that their goal is unattainable but believe that it is worthwhile to strive towards it and even partial success is an accomplishment. What they appear to have missed is the "human factors" which result in a situation where incomplete removal of a hazard, although reducing one component of the accident chain, may also reduce a person's ability to perceive and assess the hazard and to take action that will prevent the accident from occurring. Since safety or the lack of it can only be measured by the frequency and severity of accidents, we must have a method of classifying accidents.

One method is to divide accidents into three basic groups; those which involve technical factors alone, those which involve human factors alone, and those which involve both. If the human component were eliminated it would be possible to calculate the probability of accident (failure of the system) and the reliability of the estimated frequency and severity using measurable values and routine statistical methods. This,

FIG. 7



0 1
S 1
t 1
change in environment
internal or internal + external
0 1
S 2
t 2
change in environment
external only
0 1
S 1
t 2

indeed, is used effectively in computing the failure probability of complex electronic systems, utilizing such methods as the "fault tree" analysis [26]. The predictability of safety becomes more complex when human factors are considered alone or in combination with technical factors, since the human component of the man-machine system may increase or decrease the frequency and/or severity of accident.

In our approach we are saying that the commonly heard statement "all accidents are preventable" is a fallacy and wishful thinking. The statement is based on the assumption that if all "unsafe acts" and all "unsafe conditions" are eliminated there will be no accidents or that a person can achieve complete control over his own actions and his environment. The error in this reasoning is that we cannot eliminate danger. We can only replace one danger with another. Success is measured by our ability to select methods whereby the new danger results in a lower frequency or severity of accidents. Accident prevention personnel can do little to prevent accidents personally. They can, however, advise on ways to reduce the frequency and severity of accidents. Although methods to prevent a specific accident may be seen by hindsight, foresight is less clear. Hindsight, therefore, is necessary to improve foresight. Accident prevention personnel can utilize hindsight to help improve the foresight of others. It is important to realize that the person who is exposed to danger cannot be convinced of the danger unless he can be shown that such a specific action or condition sometimes results in an accident and there is a real probability that such an accident will involve him. Accidents, therefore, are necessary to accident prevention and there is a practical limit (not yet reached) below which we cannot go with our present knowledge. If a method to eliminate accidents completely is found, it will likely emanate from behavioural scientists who have not yet actively entered the accident prevention field in Canada.

How then can we reduce accident frequency and severity, and how can Human Factors Engineering help?

In studying Human Factors in Occupational Safety we will not dwell on purely technical accidents involving property damage where personal injury is unlikely to occur. The accidents we are studying are the result of action or inaction of the human component of a man-machine or man-environment system.

Our approach will be to look at the problem as a series of events or forces interacting to affect the probability or severity of possible accidents. We will start with a simple model and expand it to a point where the standard concepts of accident prevention are included then simplify it to a model which will give some insight into why the apparent removal of hazards is sometimes ineffective and why the total problem must be considered in all cases. We will concentrate primarily on the human component of the system since it is the human component which alters the technical component.

Descriptive Models

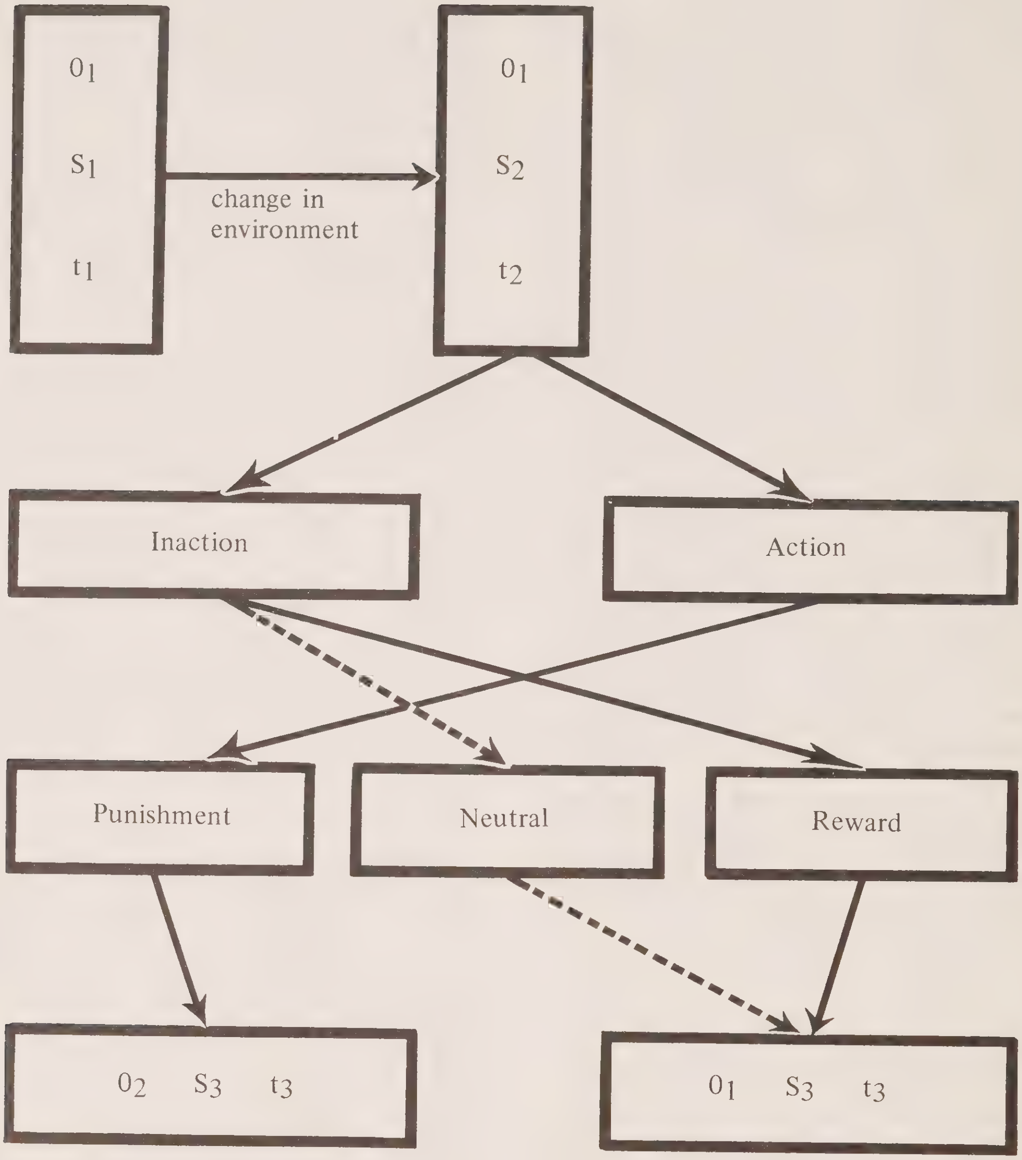
If we consider a man and his environment we can say that at any given time the human component of our system is exposed to a specific internal and external environment, both of which are subject to change. His reaction to such change and his sense of values help determine whether the result will be considered a positive or negative reward and, therefore, the action he will take when exposed to a similar situation at a future time (Fig. 7).

If we consider the human component of our system as an organism O_1 in state S_1 at time t_1 and examine his reactions to changes in his internal or external environment, we can say that, with a change in internal environment the organism(O_1) will be in a state(S_2) at time(t_2), whereas a change in the external environment only will result in no change to the state of the organism at time(t_2). Since, however, a person's internal environment is in a constant state of change and external changes, if perceived, result in changes in the internal environment, Fig. 7 can be simplified and extended as shown in Fig. 8. Under the changed environment condition he may or may not take some action. This is shown as Action and Inaction in Fig. 8. If action is taken it may or may not alter the outcome of events. If the outcome is interpreted as reward or positive reinforcement the preceding action or inaction is more likely to be repeated in the future. The organism is unchanged, except that the action or inaction is strengthened. On the other hand, if the outcome is interpreted as punishment or negative reinforcement it is less likely that the preceding action or inaction will be repeated in the future. The organsim, therefore, is different; it is also in a different state than prior to the action or inaction, since time has elapsed. If no action is taken and the outcome is not interpreted as reward or punishment but is of a neutral nature, the likelihood of increasing or decreasing the probability of inaction in the future would be unpredictable. However, as long as the neutral event was not interpreted as punishment it could be expected that inaction in the face of similar circumstances in the future would be repeated. The decision in this case is towards inaction.

The purposes of utilizing this concept of learning theory is to endeavour to find the basis from which safety starts. An accident may be interpreted as either reward or punishment.. Accidents may be the result of action or inaction by a person. In either case they may be planned or unexpected. In the case of a planned accident, motivational factors include revenge, desire for attention and many others which can only be studied and commented upon properly by behavioural scientists. (See also Fig. 6). We will not delve deeply into the reasons behind the phenomenon of planned accidents, but will comment on their result. When an accident is planned the result may be different than what was foreseen by the planner and we revert to an unplanned or unforeseen event. Serious injuries from practical jokes fall into this category.

Methods of reducing the probability of planned accidents include removal of the incentive and removal of the means. Incentive to have a planned accident again brings us back to the behavioural sciences and comment on this facet will be left for persons competent in that field. Removal of the means falls into the classic accident prevention approach of guarding everything to protect people in spite of themselves. This has

FIG. 8



0_1
S_1
t_1
change in
environment
0_1
S_2
t_2
Inaction
Action
Punishment
Neutral
Reward
0_2 S_3 t_3
0_1 S_3 t_3

some merit but as will be seen later, may reduce awareness and competence, thereby increasing the overall hazard when considering the human component of the man-environment system. It would be better to remove the desire, whether by education or by restricting the type of person who is employed in occupations where planned accidents are easily implemented.

The unplanned accident is usually composed of both human factors and technical factors. To have an accident we must have a condition which will, if unchecked, proceed to an accident situation. The accident will then occur with statistical probability. Intervening in the series of events leading to the accident is the human factor which will either increase, decrease or leave unaltered the probability that an accident will occur, and the severity of the accident if, in fact, it does occur. If the human factor intervenes, the result will be interpreted as reward or punishment. (Fig. 8). Using this line of reasoning we can say that for a given elapsed time (t) the monetary loss (L) per unit of production (from accidents) is a function of the number of times that a dangerous operation is performed (D), the number of accidents that would have occurred if nothing were done to stop them (I), the average cost of each accident (C), and the likelihood that nothing will be done (E) to effectively break the chain of events leading to the accident. This can be written as L = D.I.C.E., but it must be remembered that it applies only to a specific situation at a given time or during a given period. It is not a standard mathematical formula whereby altering D, I, C, or E will have a corresponding effect on "L". The lack of such predictability lies in the fact that a change in one component is invariably accompanied by changes in the others.

What we have is a description of the accident situation over a given period or at a given time. It may at some future date be possible to modify the formula or find a relationship between the factors, but at this stage its prime use is to emphasize that all factors are interrelated and it is impossible to alter one without automatically altering the others. An example of its descriptive use in a factory would be:

(We will consider guarded punch presses in which the only injury can be from a press that double trips, i.e. performs two full cycles when tripped once).

Loss due to punch press accidents per million units	= $100,000
Frequency of placing hand in machine	= once per unit
Frequency of machine fault causing double trip	= once per 10,000 units
Average cost per accident (compensation, medical, product damage, loss of production, etc.)	= $2,000
In this case L = dollars per million units	= 100,000
D = number of times a hand is placed in the machine per million units	= 1,000,000
I = frequency of machine fault	= 1 per 10,000 units
C = $2,000 per accident	

Since the cost per accident is $2,000 and the total cost is $100,000 it is obvious that fifty accidents occurred, but since there were $\frac{1{,}000{,}000}{10{,}000} = 100$ machine faults and the hand is placed in the machine for each unit, it is also obvious that 100 accidents could have occurred (the actual frequency being 1/2 of the expected frequency). The same answer is obtained using:

$$E = \frac{L}{D.\,I.\,C.} = \frac{100{,}000}{1{,}000{,}000 \times \frac{1}{10{,}000} \times 2{,}000} = .5$$

Since half of the potential accidents did not occur, something must have intervened. It is possible that the location of controls and the speed of the machine was such that the person could not get his hands into the die area before the ram descended the second time. It is also possible that the person had warning of the double trip and withdrew his hands in time. In either case we are speaking of human factors which must be considered in taking action to reduce the loss per million units.

The standard method of describing accidents on a macro basis with "frequency" and "severity" although interesting for comparisons serves no other purposes and is of no use in explaining "why" or offering a "better way". Perhaps we could look at the sequence of factors that must come together to create an accident situation.

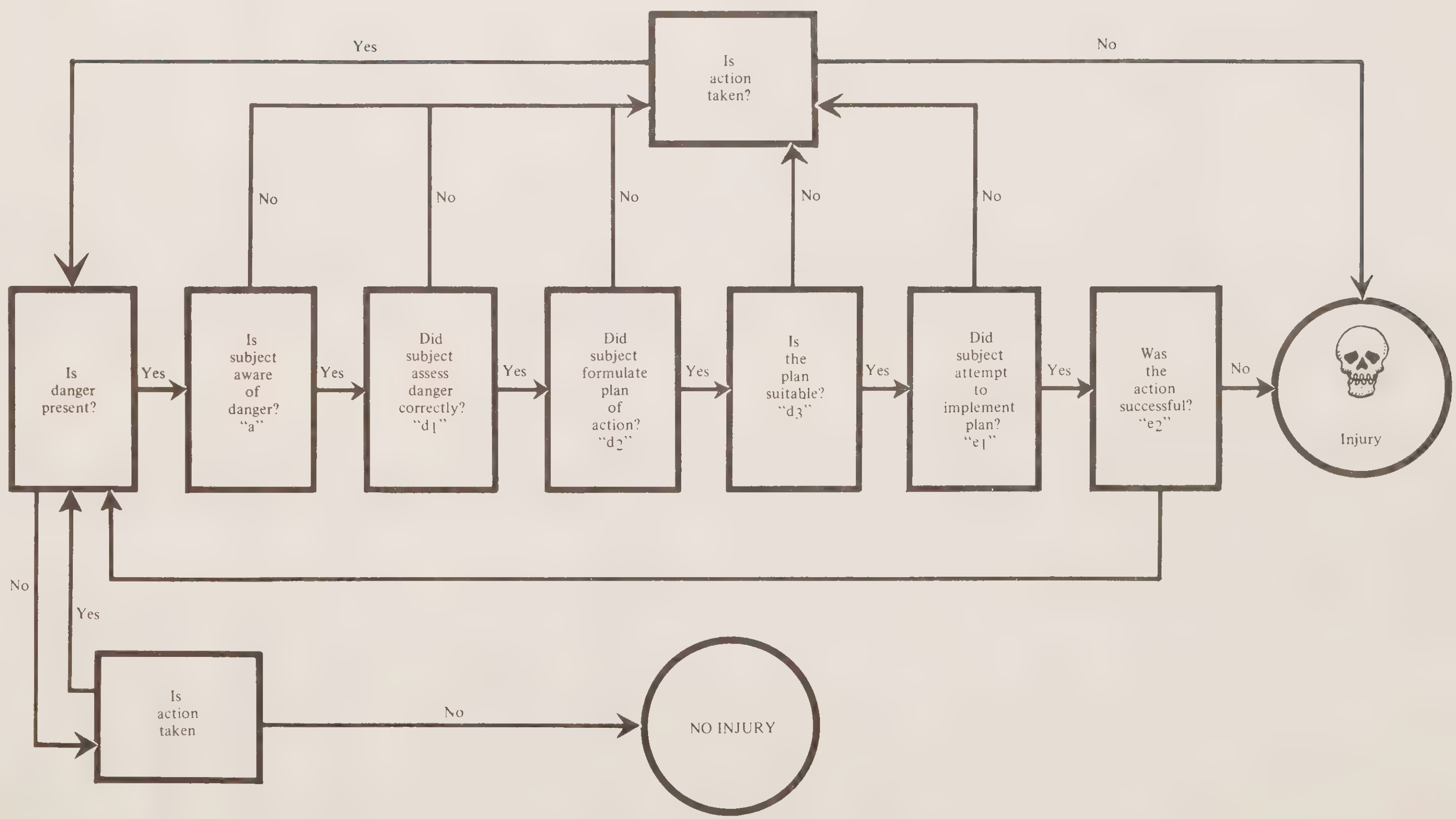
The Accident Chain

An accident is the result of what is really a series of situations that come together to form a "causal chain" or "accident chain". This has been described by others [17] and used extensively by people such as Latteiner. The weakness in previously developed causal chains is that they do not give sufficient attention to "human factors" as an accident preventer and considers them only as causes. I will explain the accident chain in a slightly different fashion than has been conventional since it lends itself to combination with a "human" factor to create the easily remembered relationship L = D.I.C.E. This relationship is easily spotted as signifying the chance aspect of accidents.

To have an accident we must first have a situation which could result in personal injury or property damage. The presence of this condition is assigned the symbol "D". Given that the dangerous situation exists there is a possibility "I" that it will result in personal injury or property damage if suitable corrective action is not taken. For each situation that results in an accident, there is an associated cost in time, money or suffering "C". This is where most causal chains stop with the result that the ability of a person to prevent an accident is ignored.

In our causal chain we will assume that a dangerous situation exists and look at the factors that may alter the chain of events. The fact that a person will be involved in an accident for one of three reasons (reached, fell, trapped) will be discussed later. Assuming that D, I, and C describe the potential danger existing at a specific time and place, we must find out what can be done to remove the hazard or reduce the frequency and severity. This is the human component of the accident chain ("E" in the relationship D.I.C.E.)

FIG. 9
THE ACCIDENT CHAIN



If we set up a situation where the choice at each step is yes or no we have the accident chain (causes and prevention) shown in Fig. 9.

If the danger potential is zero we should be able to assume that no injury will result. This is valid if no action is taken (externally or by the subject) that alters the danger potential If such action is taken we must return to the question "is danger present". If danger is present we must know if the subject is aware of the danger. If the answer is "no" an injury will result unless some action is taken. This action may emanate from an external source or may be action of the subject intended for some purpose other than reducing the danger.

If the subject is aware of the danger he may or may not assess its potential correctly; if he does not it might be assumed that an injury will result, but this is not necessarily so. As in the case of awareness, the subject may take some action or there may be external action resulting in a possible change to the danger potential which must be investigated. If the assessment is incorrect and the subject is unaware of his error, subject to external forces intervening he will proceed to the injury situation. If he does assess the danger correctly he must formulate a plan of action; it must be a suitable plan; he must attempt to implement it and he must be successful in implementing it if he is to wilfully avoid injury. The same questions arise in each step requiring return to a study of the accident potential if the answer is "no" to any question except successful implementation in which case unsuccessful action leads directly to an injury.

In effect, to alter the chain of events leading to an accident a person must take some action. The action may be unintentional or intentional and may or may not be directed at the accident chain. Any alteration in the frequency or severity may be a question of chance. To purposely attempt to alter the accident chain a person must be "aware" of the potentially dangerous situation, he must "determine" its implications correctly, and he must take some action, i.e. make and "effort" to alter the chain of events. The words "awareness", "determination" and "effort" are easily remembered since the first letters of each word form a new word "ADE" which can be associated with the standard components of training EDA. These stand for "Explanation, Demonstration and Application". Explanation is used to make the person "aware", demonstration helps him "determine" the action he will take and application of the principles taught involves "effort".

The application of "awareness", "determination" and "effort" is, therefore, merely a rewording of a standard practice to adapt it to the field of safety. It is the best method to improve a person's ability to cope with danger and interfere with the fulfillment of an accident chain which is developing, and to permit him to approach his work in a manner that will not create unnecessary accident situations.

In discussing awareness, determination and effort, these components may be of varying importance depending on the type of accident which requires correction. As previously indicated, action or inaction may play a part in causing or permitting an accident to occur.

Breakdown of Causes

Attempts have been made to divide accident causes into two basic categories, "unsafe acts" and "unsafe conditions". It is impossible, however, to develop any statistical reporting on this basis. Although studies have attempted to show that unsafe acts account for 80 to 99% of all accidents (depending on the researcher), I suggest that every accident involves both and that an accident must occur before it is possible to prove that the condition or act was unsafe. This can be easily demonstrated with a ball. If I throw a ball at a person's face it is either safe or unsafe depending on factors such as the speed and density of the ball, the distance from which it is thrown, his ability to catch or avoid it and whether he is wearing a mask. Assuming that throwing the ball was an unsafe act, it becomes an unsafe condition as soon as it leaves my hand, since I no longer have control over its movement. Many other arguments can be advanced to show the futility of talking of unsafe acts and conditions. In spite of this, these concepts are useful if the unsafe act is attached to a specific individual in a given set of circumstances. For example, a professional ball-player performs an unsafe act if he throws a hard ball at a small child in the same way as he would throw it to the catcher when someone was trying to steal home. On the other hand, if the child threw the ball at the professional ball-player under the same conditions this could only be unsafe if the professional ball-player was asleep and the ball was aimed at a particularly vulnerable location.

Similarly, driving an automobile at 100 m.p.h. in a 30 mile speed limit is not in itself unsafe. The probability of an accident depends on the driver's ability, the condition of his vehicle, the proximity of pedestrians, other vehicles, obstructions, etc.

Recognizing the weakness in the Unsafe Act-Unsafe Condition concept of recording or predicting accident probability, more detailed methods of recording accidents have been devised, some of which break down accidents to a fine degree. Although such methods are widely used, it is questionable whether the results obtained do more than uncover possible problems on a macro scale, necessitating a micro analysis for any use other than speeches. One method of coding accidents is shown in Fig. 10. Each of the categories shown may be combined with an object, e.g. "struck by a baseball".

Moody and Duggar [27] suggest another possible breakdown of immediate causes. This may be of use in determining the true fault and developing a solution. The author suggests the following types of human error:

"Error of Omission — no response is made

Error of Commission — response is made but is inappropriate (incorrect)

Excessive Variability — responses are acceptable but are[variable in intensity, duration, or frequency

Wrong Methodology — response is correct but approach in method of performing varies

Chronological Error — response is correct but is not performed at the correct time (e.g. anticipatory responses or lag in pursuit tasks)

Decisive Error — response is correct, but the less desirable of

FIG. 10

List of Basic Accident Types (Eninger) (12)

STRUCK BY

CONTACTED BY

STRUCK AGAINST

CONTACT WITH

CAUGHT IN

CAUGHT ON

CAUGHT BETWEEN

FALL TO BELOW

FOOT LEVEL FALL

EXPOSURE

OVER EXERTION

two or more correct responses is made

Non-task Performances — Response not related to demands of system"

Modification of an Old Approach

In seeking an approach applicable to human factors, several professional safety men told me that machines require guarding for one of three reasons. A person may (a) instinctively reach into an unsafe location to adjust a part; (b) trip and fall into the machinery, or (c), be in a position where he is caught when the machine starts unexpectedly.

It appeared that this concept might have a broader application and I endeavoured to apply it to other accident situations. This led me to three basic words, "reached", "fell" and "trapped". Although these causes may not be too useful for statistical reporting on a broad basis, they are useful and necessary in finding true causes for which a solution can be developed. Rather than assessing whether the person was at fault we begin by saying that if he were not there the accident would not have happened. We assume, therefore, that the accident resulted from something that he did or failed to do. This falls in line with the argument that accidents are not only caused by people but are also prevented by people. Since we must determine causes we are studying accidents which a person caused or failed to prevent. We can then proceed to methods of prevention.

An accident involves a person in association with his environment. "Reached", "fell" and trapped" explain the three ways in which the person's internal and external environment can combine to create an accident situation. (The first letters of each word can be used in a phrase "reach for time" which is easy to remember and signifies what we are trying to do in many of our accident prevention endeavours).

Reached

The word "reached" is used to explain situations where a person takes a chance either voluntarily or by reflex action. It includes situations where there is a given probability that events in the external environment will culminate in personal injury or property damage when he performs a given action. Examples of accidents in the "reached" category include (a) a person who reaches into a machine which is in motion to adjust it, remove an object, or relocate a part being worked on by the machine, (b) a person who runs on slippery floors without sufficient clear headway to stop safely, (c) a person on a scaffold who reaches beyond the scaffold without secondary support such as a lifeline. The "reached" type of accident involves action by the injured person. It could be described as an unsafe act, usually in the presence of an unsafe condition, but this would be inadequate since such description is applicable to the other two categories as well.

Fell

The word "fell" is descriptive of a person who trips or falls. Many such accidents are the result of reaching in which case they should be placed in the "reached" category. They should only be classed as "fell" when the person was not in control. "Fell" or "falling" type of accidents refer to weaknesses which the person could not predict and which occurred when he was not "reaching". Examples of falling accidents include a person who is in a situation which he could normally control but unexpectedly loses control of his motor functions, or consciousness.

This also could be described as an unsafe act in the presence of an unsafe condition since it can always be argued that the victim should not have put himself in a position where his weakness would result in injury even though it was unexpected.

Trapped

The type of accident described as "trapped" is one where the victim is in a position from which he is unable to escape when threatened by a change in his external environment. The fact that he has placed himself in this position categorizes it as an unsafe act even though he does not realize it is unsafe until too late. A dangerous condition is also present and is often, incorrectly, viewed as the cause. Accidents in which a person is trapped include, (a) a hand placed on a stationary object which becomes a pinch point when the machine starts automatically or from a remote control station, (b) a driver approaching an intersection who finds out too late that there is no caution light and collides with traffic proceeding with the green light on the cross street. In this case both drivers would be trapped by relying on a faulty device. (c) A person who trips over or runs into an object which he could not be expected to see even though he is proceeding in what would normally be considered a safe manner under the conditions apparent to him, e.g., a clear glass panel placed in a position which appears to be an unobstructed opening, and (d), clothing caught in moving machinery. In this case it is assumed that the entanglement is the result of movement by an inanimate object (the machine or the clothing). Some such accidents may, however, be more appropriately classed with reaching type of accidents.

It might also be useful to categorize combined causes such as "reached and trapped" resulting in 7 possible causal situations. If such combinations were used "Fell" type of accidents could include situations where a person fell or tripped without loss of consciousness or motor activity.

Under commonly used coding systems a study of rotary power mower accidents would show the number of accidents in which feet and hands were cut, but would offer no clue as to why. In using the three basic causes "reached", "fell" and "trapped" it becomes possible to find which "human factors" or human actions contribute to the accident.

With this method we would know the number of cases where the person reached into the rotating blade, fell in such a way as to force his fingers under the mower, or was caught when the mower started unexpectedly. We would, therefore, be in a better position to determine where improvements would likely be of most use. Under one set of results we might find that changes in the design of the housing or the blade is advisable, whereas an alternate result might indicate that the only useful improvement would be in education of the

operator. Utilizing this causal breakdown would also prove useful in job analysis or "Job Safety Analysis" (3) as it would show situations where the danger is not so much in the analysis of the job as in the analysis of what the operator might do differently than prescribed for the job. Again we get involved with the behavioural sciences since a person will, where possible, do what he wants to do or what comes naturally even though (or particularly when) it is something other than what he is told to do. Such action will, in some cases, result in an accident.

Now that we have a better understanding of our problem we must decide what to do with it. We must find how to prevent an "accident" before it occurs rather than waiting until personal injury or property damage has resulted.

Many causal theories have been advanced to explain why accidents occur. These include attitude, carelessness, and many others (Fig. 6) It must be remembered, however, that no matter what a person's attitude, environment, training, etc. if everything goes according to plan an accident will not occur since the event is under control. It is the unforeseen event and a person's inability to foresee the event and cope with it that is the prime problem we must face. Our problem is not the so called "unsafe act" or "unsafe condition", since these depend on a person's outlook and only exist in association with an accident which has already occurred. If we can agree that an accident cannot occur if everything proceeds as planned we can arrive at an accident cause as follows:

"An accident can only occur to a person who is unable to avoid or cope with an unforeseen or unplanned event. His ability to cope with such events is a human factor in accident prevention which varies with his natural and learned abilities."

To avoid or otherwise cope with an unforeseen or unplanned event a person must be aware of its occurrence and be able to do something about it. We can now say "The probability that a person will be involved in an accident is a function of his ability to cope with or avoid an unforeseen or unplanned event". We can also say that "the probability of a person being involved in an accident is greatest when he has not reserved sufficient attention and ability to cope with or avoid the consequences of an unforeseen or unplanned event".

The cause will fall in one or more of the following categories which are listed in order of difficulty in understanding and correction. Although we have looked at the last three previously we will now see how they fit in the "awareness", "determination" "effort" concept.

1. Deliberate — Accident planned, trap set purposely. (Result of action or inaction)
2. Reached — Subject extended self beyond reasonable limits. (Action creates situation which cannot be corrected.)
3. Fell — Lost control of muscular functions or lost consciousness. (Inaction, external danger proceeded as would be expected.)
4. Trapped — Unexpected change in external environment without time for escape. (Inaction or action, but unable to avoid change in external environment.)

Deliberate

This is really a special case of "reached" or "trapped" as opposed to unintentional accidents which may be reached, fell or trapped. It is considered separately since the corrective action may be different. When a person deliberately creates a situation that will result in injury to himself or another person it may be for revenge, attention or other factors in the realm of the behavioural sciences. If the person creating the accident situation intends to injure himself, "awareness", "determination" and "effort to prevent" on the part of other persons may be temporarily effective, but whether it is of any long term use is a question for the behavioural sciences. If the deliberate act is directed against another person, that person must protect himself if he is to avoid injury. To be aware of the danger he may utilize one or more of his senses including tactile, visual, auditory, olfactory or taste, depending on the signals emitted by the danger. A question that might be asked in this regard is whether a person who has always worked in a protected environment is more or less susceptible to injury in the presence of practical jokers or other persons who might deliberately create an accident situation. The question of experience or training must again be considered when looking at the subject's ability to "determine" his action, which includes assessing the danger and planning his course of action. Similarly, experience and training play an important role in corrective "effort" or in his ability to avoid injury. It would appear that where an accident is the result of an intentional act, and although punishment may be of use in deterring the action of the perpetrator of the situation, successful avoidance must rely on the ability of a person to prevent the consequences through the effective use of this senses and training in appropriate muscular functions. (Human Factors) Guarding of machines and removal of persons who might intentionally create accident situations are also effective methods. The only method commonly utilized today is machine guarding, indicating the need for increased involvement of behavioural scientists and Human Factors Engineers to ensure that the human component of the system is adequately considered.

Reached

A "reached" type of accident is one in which a person places himself in a position whereby he has not retained a sufficient reservoir of attention and ability to cope with an unforeseen or unplanned event. Most accidents are likely to fall into this category since they include all accidents involving a deliberate action by the person involved (exclusive of deliberate accidents). The subject is aware of what he is doing but he may not be aware of the consequences. Experience and training can assist his awareness of the dangers associated with his action, making it possible for him to develop methods whereby his senses can be used most effectively to warn of danger or he can develop alternate and safer methods of approaching the task. (See Fig. 11). His senses can also be extended by the use of microscopes, thermometers or additives that warn of the presence of danger. The addition of pleasant flavouring and colouring to potent drugs used as medicines can be cited as a reverse application of this

principle, which may increase the danger to young children having access to such drugs.

Determination of action to be taken to prevent a "reached" type of accident may involve mechanical guarding or training and experience for the individual. Training may include practice in utilizing special tools to ensure that no part of the subject's body will be placed in an unsafe position.

Effort to prevent a "reached" type of accident may be applied at various points in the accident chain depending on the specific nature of events and their likely consequences if unaltered. In the case of a fast moving press, a gate or pullback guard if properly adjusted will prevent the subject from reaching into the unsafe area. On the other hand, an audible warning for a slow moving press may be sufficient for a person to check his reaching action and withdraw his hands in time. On this same point, training and experience accompanied by a fear of being trapped by the descending ram may be more effective in preventing accidents than the installation of a mechanical guard which has a predictable failure probability and which may result in the subject operating with a lower level of "awareness", "determination" and "effort".

Fell Type of Accidents

When considering "awareness" in a "fell" type of accident we often revert to a "reached" category. If, for example, a person is aware of a physical condition whereby he becomes unconscious without warning, climbs a ladder and falls as the result of such an attack, he has "reached" or extended his capacities too close to their limit with no secondary line of defence in event of failure. If, however, he wears a lifeline at all times when on the ladder and falls as a result of unconsciousness combined with a faulty lifeline, it would be a "fell" type of accident. Awareness in this category depends primarily on learning and experience. Determination of the hazard is again learning and experience, since a "fell" type of accident can most effectively be prevented by action implemented prior to commencement of the fall. In cases where a person has started to fall, learning and experience play a significant role in determining whether the safest action is to continue falling or to attempt to recover. The appropriate decision depends on the person's assessment of the likely outcome of each action.

In making an effort to prevent or correct a "fell" type of accident, experience and training are essential. Once a fall has commenced there is little or no time to learn new muscular responses or to inhibit responses previously learned. The recovery in most cases must be through unconscious reflex type action, implementing a previously learned muscular sequence. Recovery from tripping over a rope falls into this category.

The "fell" type of accident is one involving the failure of the body, when taking normal precautions, to comprehend or cope with an unforeseen danger.

Trapped Type of Accidents

To be considered a "trapped" type of accident a person must be deliberately or otherwise in a position where an unforeseen change in his environment creates a situation from which he cannot escape. Such accidents could include a situation where a person's hand is in a position which does not appear dangerous and is caught due to sudden starting of a machine by automatic controls. Awareness can be improved by experience and training as well as use of signs, protective guards, auditory, visual or other signals prior to starting the machine or by a preliminary warning movement.

Determination of hazard and remedy is primarily a question of training and experience. Effort to prevent or correct the situation can also be improved by training and experience through improved muscular co-ordination.

A Comparison of Limited, Normal and Excessive Alertness

As indicated previously, there appears reason to believe that a person is most likely to be involved in an abnormally high number of accidents if he is unaware of danger that may arise (this person could be described as accident prone), if he is aware of the dangers but incapable of avoiding or overcoming them, or both. In the lower levels of alertness he is subject to his environment, but in the higher levels he may manipulate the environment to increase or decrease the dangers. He may also attach too much importance to minor dangers or too little importance to major ones. In addition, he may be working at the limit of his capabilities.

Conversely, a person is least likely to be involved in accidents if he becomes competent in the task he is performing, maintains his competency by frequent practice, testing his skills in mock danger situations and maintaining a reservoir of attention and ability to handle unforeseen situations that might arise, i.e. compare to a well trained army that maintains reserve forces and is practiced in retreat and regrouping as well as offensive techniques.

Human factors are, for the purposes of this paper, those factors which affect a person's ability to attend to a change in his environment whether the effect of the change be positive or negative. It includes the effect that the person's action has on his environment. It does not, however, include inanimate things except in so far as they affect the animate.

The brain becomes the central processing unit receiving messages from both the internal and external environment, (47) determining upon past experience what action should be taken and implementing that plan of action. Messages are received from both the autonomic nervous system and the central nervous system. The messages received from the autonomic nervous system permit the person to attend to changes in his ability to react to a situation, examples being hunger and thirst, or general deficiencies due to allergy or some other factor. Such signals are normally of a negative nature, indicating a reduction in ability to attend to a change in the environment (although some writers indicate that there are exceptions such as alcohol where it may result in faulty signals). In effect, the person receives a warning that his ability is altered along with a change in the hierarchy of items to which he must attend.

Many types of signals may be received by the central nervous system including taste, visual, tactile, auditory and

FIG. 11

Decision to perform a task is based on the answer to five questions (5)
(Burner & Rockwell)

1. What are the task requirements?

2. What are my own capabilities relative to the task?

3. What will I gain if I attempt the task and succeed?

4. What harmful consequences will I suffer if I attempt the task and fail? and

5. What will be the loss if I decide not to attempt the task?

olfactory stimuli. The processing of this information permits, with experience and training, messages to be sent to actuate muscles, as well as preparatory action of the glands by way of the autonomic nervous system. A hierarchy [15] of attention is present at all times and one of the purposes of human factors engineering is to ensure that appropriate attention is focused on those factors which will not only maintain production but will prevent injury. In considering the question of human factors it is easy to see that the frequency or severity of accidents can be reduced by increasing a person's level of attention (particularly to those items that could affect his safety) by increasing his ability to react correctly to situations that might arise, or by reducing the number of factors to which he must attend and which could be dangerous to his safety.

No matter what we are doing in an accident prevention program, we are utilizing one or more of the following concepts; improving awareness, improving ability, or reducing the hazard.

A moderate number of hazards may, within limits, increase a person's ability and result in a total accident experience less than the sum of its parts, but there would be a breaking point. This hypothesis is illustrated in Fig. 12.

Low Levels of Alertness

Deep sleep is considered to be the condition under which a person is least aware of his environment [7]. There are five levels of sleep; (1) drowsiness, (2) light sleep, (3) medium depth sleep, (4) and (5) deep sleep. We will first examine the subfactors of which the Human Factor is composed, under conditions of deep sleep, since this condition is at the lowest level of alertness and the person can, therefore, have no effect on the values of D, I, and C. He is, in effect, at the mercy of his environment.

"Awareness" — A person in deep sleep will not be aware of a danger that is creeping up on him. It takes a loud alarm bell or some other significant change for his reticular activating system to bring him to a state of alertness where he can do something about the impending danger. Protection for a person in deep sleep or for a person completely engrossed in an interesting task must come from an external source. Fire alarms are often advocated to awaken persons when fire threatends but the experience of persons who have not heard a telephone or alarm clock indicates that fire alarms may also be of little use to a person in his deep sleep period, which is likely to cover 50% of the time between 11 p.m. and 3 a.m. Periods of wakefulness and light sleep with peaks at 50 to 90 minute intervals are interspersed with the deep sleep and it might be argued that during the period that a fire alarm is useful a person's olfactory sense would likely be as effective. The new detectors employing radioactive sources, however, may be of some use mounted in a bedroom (particularly when carbon monoxide is the prime contaminant), since they may sound an alarm when the concentration of gases is insufficient for olfactory stimulation, thereby reducing but not eliminating the danger of suffocation by smoke while sleeping. Additional people in the dwelling due to varying sleeping patterns may be more effective than alarm systems. This argument applies only to private dwellings where smoke will spread quickly to all rooms. It is not intended to discourage the use of centrally operated alarm systems in hotels and other large buildings.

A similar example relates to a person completely absorbed in a task (e.g. reading) who is oblivious to his surroundings for periods of varying length.

"Determination" - d_1 = assessment of danger. In deep sleep a person cannot assess danger adequately since he is unaware of its presence. In increasing levels of awareness the nature of the danger determines his ability to assess its potential. Olfactory, tactile and auditory stimuli are likely to be noticed before visual stimuli and can serve as cues to assess the need for increased awareness. In our example of the fire alarm, in the absence of olfactory stimulation a person may associate the alarm bell with some undesirable noise (alarm clock or telephone) and pull the covers over his head, thus decreasing his ability to detect the olfactory cue in time to take appropriate action. A person's assessment of danger in periods of partial wakefulness can be reinforced by alarm systems including a person's prior knowledge of dangers that may arise and his ability to assess the danger, although the sensory stimuli are incomplete. Pulling a blanket over one's head is a case of guarding against one exposure in a manner that makes the subject more vulnerable to another hazard.

d_2 = attempt to plan. This is dependent on both time and experience and is useless in the absence of "a" and d_1. The sooner a person is aware of a danger, the more likely he will be able to deal with it effectively.

"Effort" - e_1 = attempt to implement. The attempt is possible assuming that the plan is formulated, but not in deep sleep.

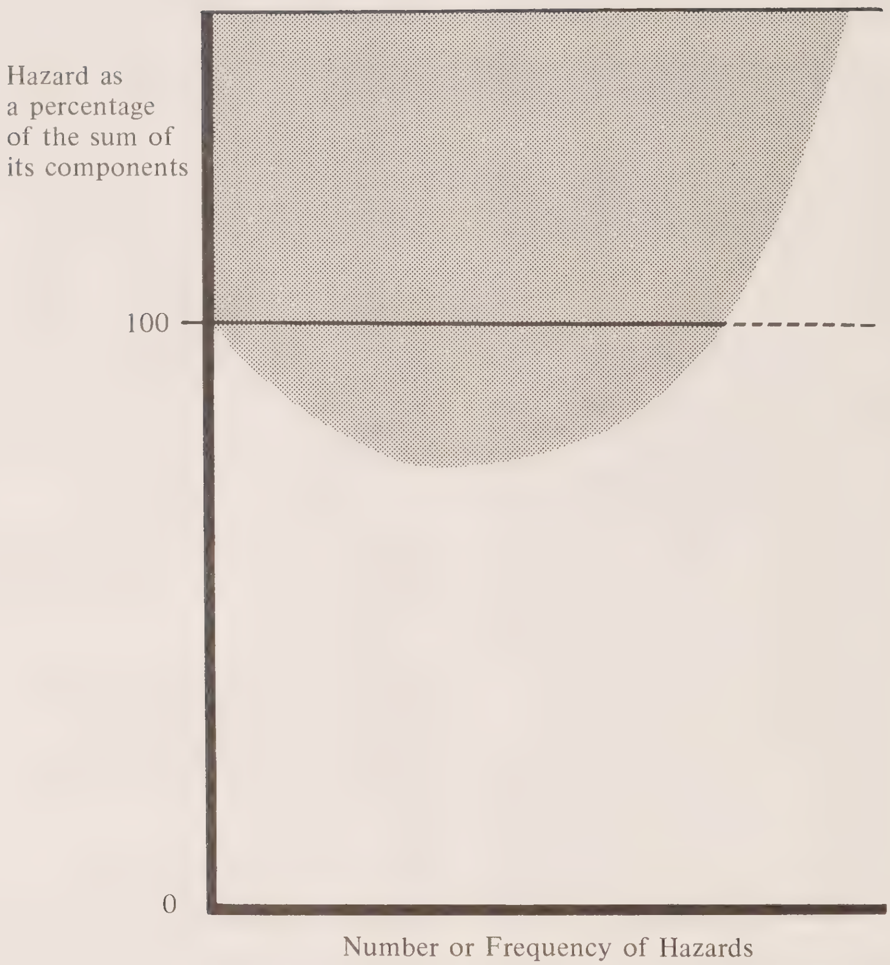
e_2 = ability to implement. A person in deep sleep cannot implement a plan even if he were capable of formulating it since successful implementation necessitates receipt and processing of stimuli which is only possible at higher levels of alertness.

In summary, if any action is to be taken to alter a developing accident chain when a person is in deep sleep or otherwise incapable of receiving normal stimuli signifying the approach of danger, this can only be accomplished by a sentry that will either protect the person or arouse him in sufficient time that he can formulate and implement a successful plan of action.

Normal Levels of Alertness

"Awareness" — Under normal levels of alertness a person will likely be aware of any change in his environment unless he is completely engrossed in a specifiç task in which case it must be considered that he has a low level of alertness in so far as his total environment is concerned. This raises the question of total vs localized attention. A squirrel is aware of his total environment, a talent that is necessary for his survival. A cat, however, in stalking a mouse may be unaware that it is being stalked by a panther. Concentration on visual inputs may block other sensory cues. The cat is similar to the person who is intently watching the car ahead of his and is unaware of approaching danger. The defensive driver is like the squirrel, he watches all the traffic and therefore can usually predict what

FIG. 12



Hazard as
a percentage
of the sum of
its components
100
0
Number or Frequency of Hazards

FIG. 13
THE ALERTNESS SURFACE

(Moody and Duggar) (27)

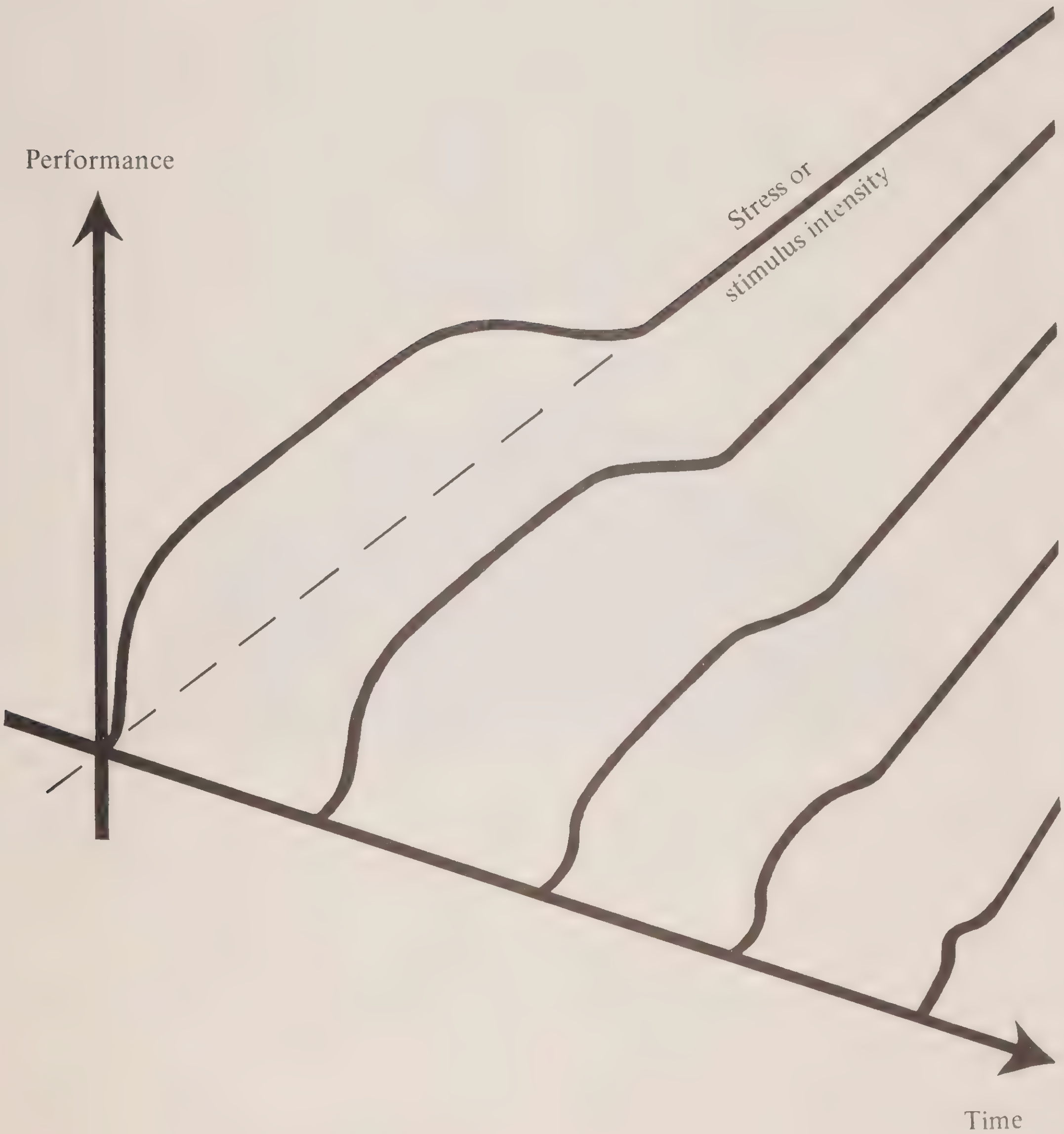
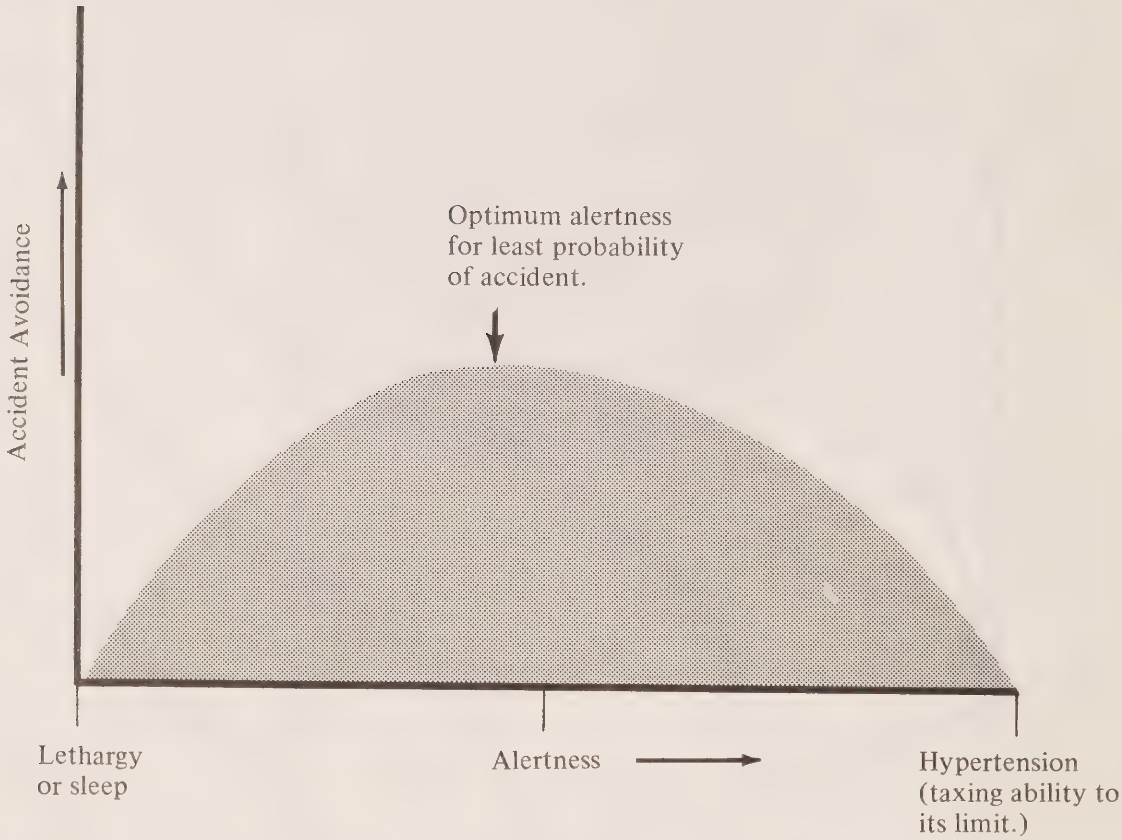


FIG. 14

Possible effect of alertness on accident avoidance



the vehicle ahead of him will do. In so doing he can also protect himself from the driver behind him and have a beneficial effect on the entire traffic pattern.

"Determination" — d_1 = assessment of danger. At normal levels of alertness a person's assessment of danger is likely to be at its best. He is sufficiently alert to be able to analyze the situation properly and to determine the relative effects of action vs inaction. To assess any situation correctly he must understandthe potential danger through past training or experience. d_1 can, therefore, be improved by education both practical and academic.

d_2 — attempt to plan. A normally alert person is in the best position to draw on his stock of planning components and formulate them into a plan. The exception being when he is already operating at the maximum level appropriate to his level of alertness, in which case planning must be accompanied by a reduction in some other activity. Previous successes and failures help determine whether he will attempt to formulate a plan. This factor can be improved by the efficient implementation of all tasks to ensure that a cushion of attention is available for planning without the need for curtailing other activities. Practice in implementing successful plans is also useful in building confidence and therefore increasing the probability that he will attempt to formulate a plan.

d_3 = ability to plan. As in the previous cases, planning ability should be at its best under conditions of normal alertness. Training and experience are the best methods of improving planning ability. An alertness cushion is also required here.

"Effort" — e_1 = attempt to implement. Assuming that the plan has been formulated, the person would likely attempt to implement it unless he was afraid of the consequences of failure. Successful completion of similar plans is helpful in building confidence. Training and experience are helpful here.

e_2 = ability to implement. As in the previous factors, under normal levels of alertness a person's ability to implement a good plan should be at its best. This ability can be improved by training and experience. The most likely problem is when a person is already working at peak capacity and has no reservoir or cushion in his capabilities.

In summary, training and experience should be the most useful methods of improving a person's ability to prevent accidents when he is normally alert. In addition, he must leave a reservoir or cushion of his abilities to attend to unforeseen situations that might arise. Mechanical and physical aids, although not mentioned under each item can be used effectively to extend a person's senses and his physical abilities. Examples include eye glasses, hand tools, and additives that will stimulate olfactory receptors.

Excessive Levels of Alertness

Although very high levels of alertness might be considered beneficial, they may be detrimental. The problem being that the person may endeavour to solve all the problems that come to his attention and leave no reserve for attending to the unusual. He may in these attempts not do any of the jobs properly and may institute action which increases the probability of danger, perhaps to such an extent that increased alertness is more than balanced by an increase in danger, frequency, and severity, with a reduction in available awareness, determination and effort resulting in a net loss.

"Awareness" — Under high levels of alertness a person may be aware of insignificant changes in addition to those that are important. He may attempt to take action on all items to maintain his level of alertness, arriving at a balance which leaves little or no alertness cushion for unusual dangers that may arise. An understanding of the items that are least important and the importance of maintaining attention to the total environment is essential to reducing accidents in this case. Provision of sentries or other methods of dealing with unusual dangers is just as important here as it was in low levels of alertness.

"Determination" — d_1 = assessment of danger. In this situation the person may be so engrossed in other problems that he may not appreciate the danger of the novel situation. Alternatively he may give it too much weight and in trying to deal with it may disregard those dangers he previously had under control. If, however, he has maintained a reservoir of attention he may be able to handle the novel situation adequately. Complete knowledge of a control system, utilizing the human factors approach in the shape and location of control mechanisms [28] is effective in ensuring that the visual system is not distracted from important features of the existing and novel situations. There is, however, a limit beyond which the utilization of a person's senses cannot be used to increase his assessment of danger.

d_2 = attempt to plan. This is dependent on the available reservoir of plan components plus the reservoir of attention available for planning. As in "d_1" proper utilization of human factors can increase the available attention for planning. Past experience can be helpful particularly if the required plan has become a routine program [47].

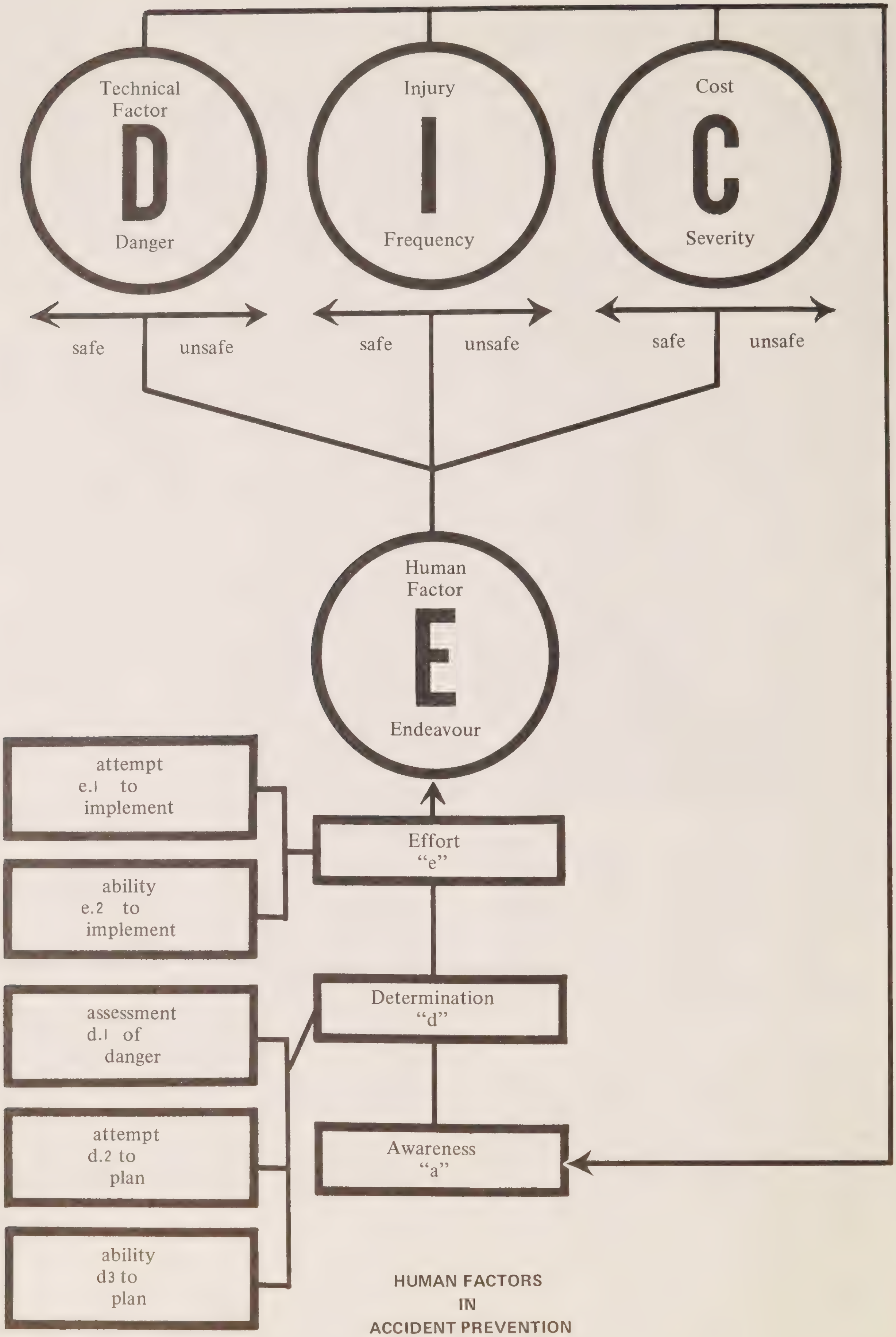
d_3 = ability to plan. This is also dependent on the available reservoir of successful plan components and past experience in implementing similar plans, plus the reservoir of attention available for planning.

"Effort" — e_1 = attempt to implement. At high levels of alertness a person may be expected to attempt to implement a plan once it is formulated.

e_2 = ability to implement. Ability to implement a plan at high levels of attention may be hampered by premature action or errors due to the high level of co-ordination required or by trying to do too many things at once. Human factors engineering can distribute the work load over the various sensory systems to facilitate training and improve performance of multiple or complex tasks during high levels of alertness.

In summary, the best method of avoiding accidents should be through experience and training, utilizing human factors engineering to take full advantage of all sensory systems, practicing the action to be taken under simulated danger conditions that will permit development of defensive measures for use when real dangers arise and assist in maintaining a suitable level of alertness. When real dangers may arise, a cushion of alertness must be maintained by the individual or through human or mechanical assistants capable of handling or postponing the additional hazard if it materializes. Under this

FIG. 15



HUMAN FACTORS
IN
ACCIDENT PREVENTION

concept hobbies may be beneficial to accident prevention, particularly when the skills necessary for the hobby are similar to those required to prevent accidents.

Possible Relationships in Accident Prevention

A person's decision to proceed with a task is based on his assessment of the magnitude and probability of positive and negative rewards associated with the task. He may over-estimate the positive aspects and under-estimate the negative or vice versa. To some people punishment or injury is a form of reward, and this must be considered when assigning persons to a potential dangerous task. For each person at a given time there is a relationship between decision to proceed (p), his assessment of the reward (R) and his assessment of risk (r). Increasing the reward will likely increase the probability that he will proceed, and increasing the risk will likely decrease the probability. It must be remembered, however, that the person manipulating R and r may have a different set of values than the person who is to perform the task.

This relationship is used only for illustration purposes since it is, at this stage, impossible to predict the inter-relationship or concrete values of the variables. If a formula were developed the value of p would, of necessity, be arranged to never exceed unity.

A possible form of such a formula could be $p = KR^{x} - Kr^{B}$, with values of p not to exceed unity when positive, but having no limit when negative. This would emphasize the case where a person would not only decide that the task is too dangerous but would take action to prevent other persons from attempting the task.

Accident prevention programs can be useful in helping a person realistically assess all factors associated with reward and risk (positive and negative reward) in the situation under consideration. If R can be increased or r decreased, it has been suggested that a person's willingness to perform a task should be increased. Similarly, a person who is determined to perform an unsafe task may reconsider if alternate tasks are offered that provide a safer method of achieving an equal or greater reward. Determining whether the reward justifies the risk assists in finding ways to increase reward or reduce risk.

A Simplified Model of Human Factors in the Accident Chain

It appears reasonable to believe that; "The success or failure of an accident prevention program is determined by its effect on a person's ability to attend to those dangers in his environment that have not been eliminated, and those that have come into being as a result of the program".

Putting together the concepts advanced on previous pages we can formulate a simplified model utilizing the relationships advanced in the paper along with concepts that have been utilized in accident prevention for many years. Figure 15 shows this model in schematic form and it should be recognized that every step of a job safety analysis should be examined in the light of this model. If we recognize that any accident situation is composed of technical factors and human factors we can break these down into more detailed components as indicated earlier in this paper. First, we can say that technical factors relate to the total environment both external and internal and they are constant at any given time and place. The human factors relate only to the internal environment and how they react with the technical factors through the embodiment of muscular action. We have mentioned the relationship D.I.C.E. in which E is the human factor. This human factor is broken down into "a", "d" and "e". If a person is to make an intentional effort to alter his environment in any way he must be aware of the situation and he must determine what to do about it. To determine his course of action he must assess the danger properly, he must attempt to formulate a plan, and it must be a useful plan. This awareness and determination is useless unless it is put into action through effort, in which case we involve an attempt to implement and the person's ability to implement, all of which were explained earlier. When the effort to implement a plan is made it takes the form of action which may be considered a safe act or an unsafe act, depending on the intent of the person and his ability. If we now look at the technical factors and use "D" to describe the extent of the existing danger (which may be considered a safe condition or an unsafe condition) then the action of the person will drive the dangerous condition to a higher or lower plateau or leave it unchanged. An unsafe act will drive it to a higher plateau creating a condition which is more unsafe, whereas a safe action will drive the danger to a lower plateau or perhaps eliminate the danger completely. If "I" is used to describe frequency of accident we can say that the dangerous situation will result in injury with a determinable frequency. The frequency may be altered by human action and we therefore say that "I" represents the frequency of accident that is likely under the environmental conditions which exist at a specified time. Action by a person may drive the frequency to a higher or lower plateau and again we can say that an unsafe act will drive it to a higher plateau whereas a safe act will drive it to a lower plateau. It might also be noted that if an accident occurs it would be the result of a person reaching, falling or being trapped (recall the reached, fell, trapped, concept mentioned earlier).

If an accident occurs it will involve a cost in personal injury, property damage, or both and this cost "C" can be considered the severity of the accident or injury. If we again look at the action performed as a result of a person's awareness and determination this action may drive the severity to a higher or lower plateau. If it drives it to a higher plateau it can be described as an unsafe act, whereas if it drives it to a lower plateau it can be described as a safe act.

If a person's action reduces the severity but increases the frequency we then have an action which is both safe and unsafe and we must be prepared to consider the entire picture in determining if the net result is an improvement. It could be argued that since I and C are related to D that they are unnecessary in the model but I submit that they are necessary for a proper understanding of any potential accident situation to ensure that all factors are considered and to emphasize the danger of adjusting one component of an accident chain without giving due consideration to the others. In our earlier

example of the baseball we can look at the model and say that to decrease the severity of injury it is necessary to practice throwing and catching the ball in which case the frequency at which a person's hand is struck with the ball is much greater. We are increasing the frequency but in so doing have decreased the severity which is the desired result since the total experience of the lesser impacts is less punitive than the fewer impacts of greater severity to which the inexperienced ball player is exposed.

CHAPTER IV

APPLICATION OF THE PROPOSALS

Now that we have looked at some of the ways in which human engineering can give us a better insight into accident causation, prevention and avoidance, we will examine some existing accident prevention literature to uncover possible weakness and see how the human factors approach can remove the weaknesses and provide a more enduring structure.

Examination of Safety Programs and Research Reports

1. National Research Council Motor Vehicle Accident Study Group [44] Technical Note No. 2 (Our Fig. 16).

The graph shows level of tension or anxiety as measured by the galvanic Skin Response under normal driving conditions as a function of years since drivers' license obtained. The fitted curve indicates that a novice driver is five times as tense as a driver with 10 years' experience. The twelve results from which the curve was plotted, however, show such scatter that additional tests would be necessary to attach any significance to the curve.

The plotted curve may be completely erroneous since there are only two observations that appear to be related to two or three years' experience, one having an anxiety rate near 25% and the other almost 100%. It is possible that a more statistically accurate curve would follow an "s" pattern. Although factors such as age do not appear to be considered the curve is probably correct in showing the anxiety rate reducing with years of experience. Since many studies have shown a reduction in accident experience with increased age it could be concluded that alertness is not related to a person's ability to avoid an accident. Such a conclusion is, however, inappropriate since an inexperienced driver's nervousness, although possibly related to awareness of change, is not necessarily a measure of his attention to changes requiring his attention. In fact there may be an inverse relationship.

Fig. 17 shows that the person least likely to be involved in an accident drives approximately 5 m.p.h. faster than the average rate and that his involvement rate at 10 m.p.h. faster than average is similar to his involvement rate travelling at the average rate. Assuming the results are statistically significant and that extraneous variables were held constant, these results support the concept that probability of accident is a function of attention since a driver when passing other vehicles is likely to be more alert than if he is moving with the flock. He is more likely to be aware of changes in his environment while, at this slightly increased speed, the other variables are relatively unchanged. At greater speed differentials, however, his awareness will not likely increase in proportion to the increase in potential danger, severity of accident and the decrease in his ability to cope with unforeseen or unplanned events. This would cause an increased accident involvement which again coincides with the experimental results.

Safety Philosophy of Company X

(1) "Positive belief that all personal injuries can be prevented". I believe this is erroneous and completely unnecessary to a safety program since it is unlikely that we will, in the foreseeable future, be able to eliminate the probability of accident completely but I will agree that such a statement can be applied to all accidents using hindsight and that "only foresight can eliminate the need for hindsight". This statement may be a punishment to a person who is the victim of statistical odds. It must also be recognized that economic and other factors must be considered. A systems approach might say that there are some accidents, particularly ones which do not result in permanent disability where we must accept a certain probability of accident as reasonable and necessary to maintain an optimum level of awareness, determination and successful effort, for the purpose of keeping accident experience at the lowest level possible.

(2) "An acceptance on the part of management, supervisors and foremen of their responsibilities to prevent personal injuries". Since such persons can have an effect on the number and type of hazards that are present and their reduction through provision of a safe environment, training, etc. the statement is valid.

(3) "A conviction that it is reasonably possible to safeguard all construction and operating exposures which may result in personal injuries". This statement may be valid for long term operations but when considering special orders or short term tasks it is necessary to compare the severity and probability of injury to the cost of the remedial action as well as the effect on a person's ability to cope with unforeseen or unplanned events, and the accident experience that may be associated with the construction of the proposed safeguard.

(4) "A recognition that it is necessary to train all employees to work safely and to understand that it is to their advantage as well as the company's to work safely, and that they are expected to co-operate in doing so". Although this statement is basically correct, the last phrase suggests "be safe or else" which detracts from the positive nature of the first part of the statement. The statement is valid since it emphasizes the employee's role in preventing accidents through keeping hazards to a minimum and learning to deal effectively with those that remain.

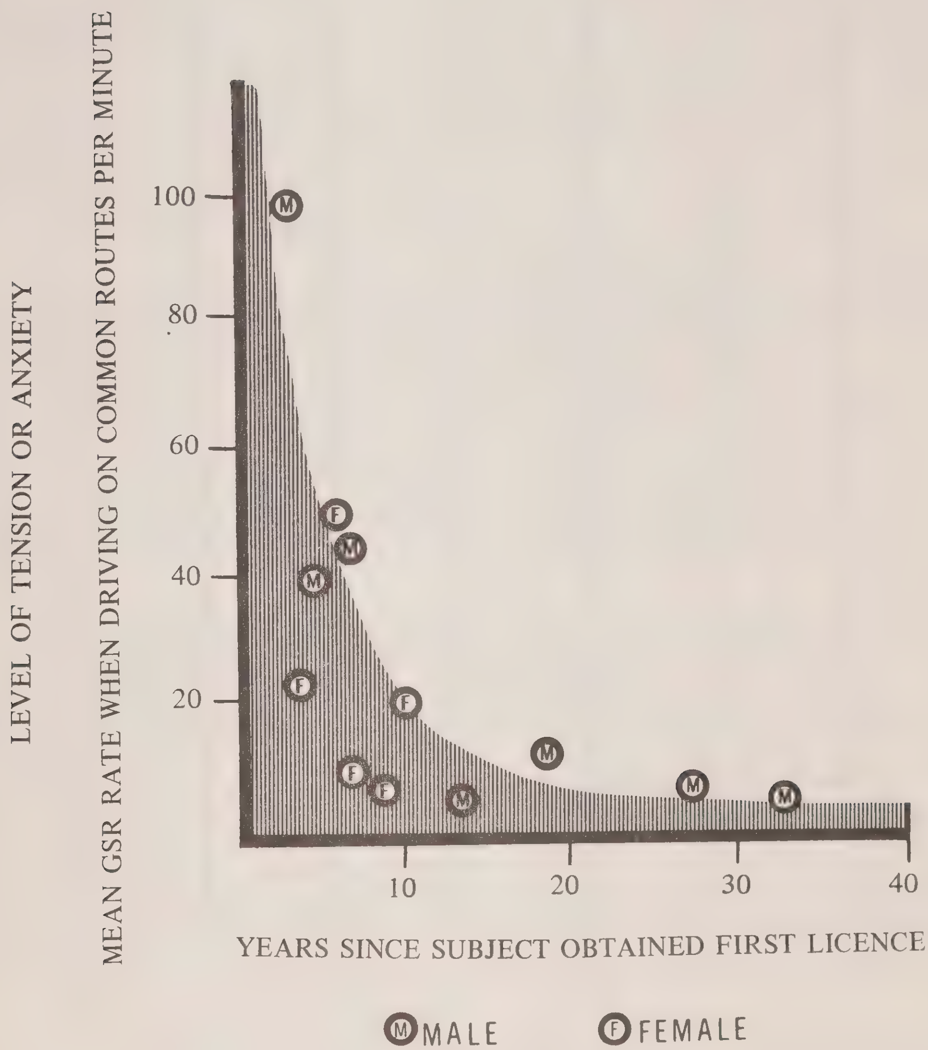
(5) "An acceptance of the fact that it is good business from the stand-point of both efficiency and economy to prevent personal injuries". On face value this appears to be a sound, logical statement. There is, however, reason to believe that once the frequency and severity of accidents becomes very low, a person's ability to cope with remaining dangers will increase associated with a lower level of attention, unless some artificial means is found to maintain an optimum level of awareness, determination and effort. The cost of maintaining awareness or attention at low levels of accident experience may be prohibitive in some cases. The company's statement is valid at the accident rates presently existing and there are signs that it is valid (for all practical purposes) for lost time injuries but this may not be true for all injuries.

Bell System

"No job is so important and no service is so urgent that we cannot take time to perform our work safely". This sums up a sensible safety philosophy in a concise and accurate way. It eliminates unnecessary verbage, duplication and detail while

Fig. 3
Tech. Note No. 2
N.R.C.
Motor Vehicle Accident
Study Group
Ref. 44

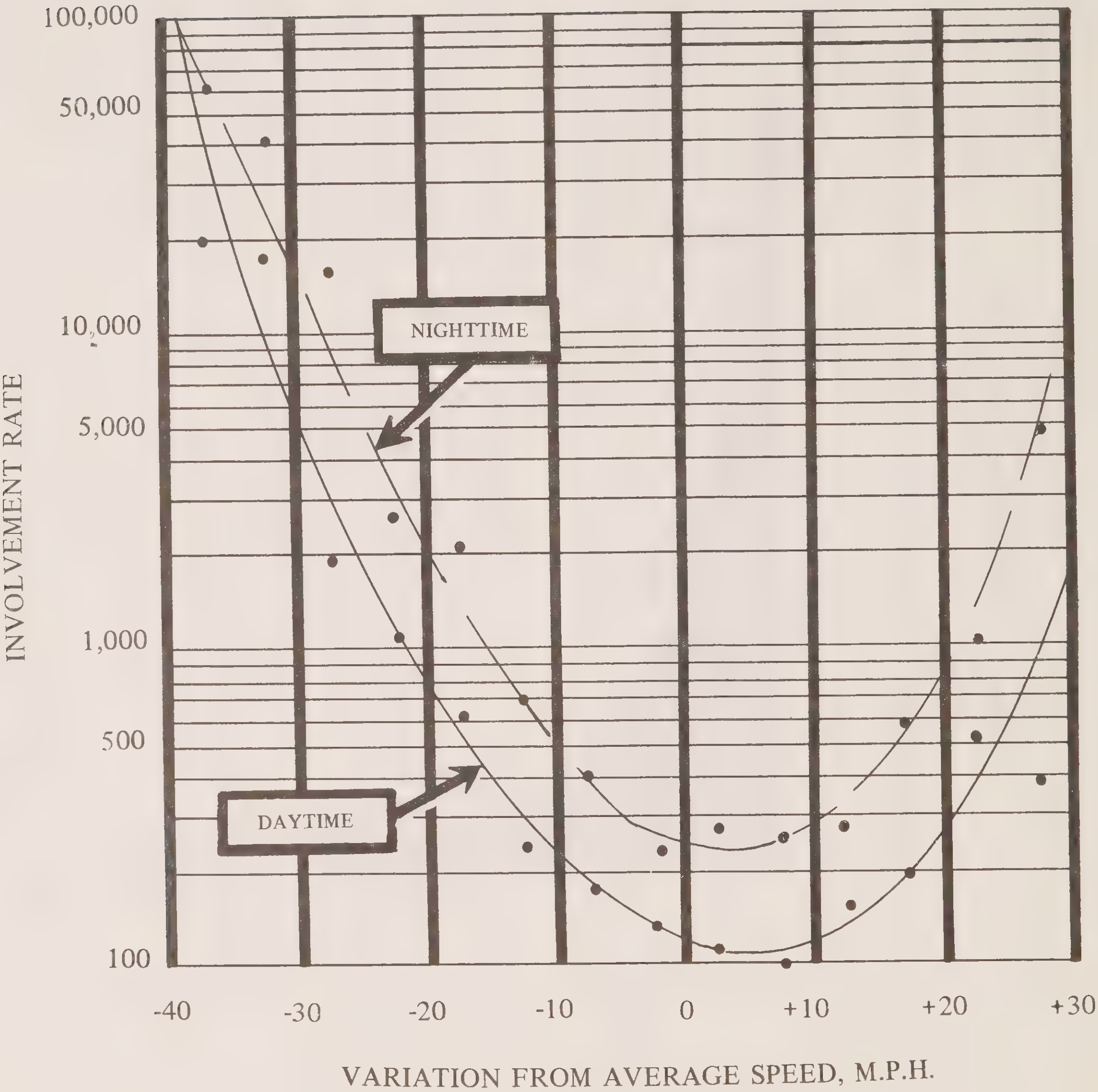
FIG. 16



SUBJECTIVE MEASURE OF DRIVING EXPERIENCE

FIG. 17

FIG. 10
TECH. NOTE NO. 9
Ref. 45



INVOLVEMENT RATE BY VARIATION FROM AVERAGE SPEED
ON STUDY SECTION, DAY AND NIGHT

retaining the required message. It is completely consistent with the causal, prevention and avoidance relationships, particularly in the case of multiple dangers and where abilities to deal with dangers vary, not only between individuals but for each individual. It emphasizes the importance of working within a person's limits and retaining a reservoir of attention for the unexpected. It is complete in its intended purpose and is not designed to facilitate comparison or measurement of results.

Examination of Safety Textbooks "Industrial Accident Prevention by H.W. Heinrich"(17)

This book has often been quoted as a classic in safety literature. Heinrich's analysis of the problem and his listing of direct and underlying causes cannot be disputed. There is no question that his approach to accident prevention is basically sound and has been proven in practice. There is, however, a weakness in his argument. Although he mentions human factors, education and the need for utilizing the talents of behavioural scientists he continually reverts to "unsafe acts" and "unsafe conditions" as the villain requiring attention. This approach completely ignores the skill factor and immediately considers an unsafe act to have been performed merely because cases can be cited of persons being injured when performing such acts. Every action or inaction of our waking and sleeping hours can, under this concept, be labelled unsafe acts. Whether a child is holding a firecracker or an adult crosses a railway track on the way to work is not in itself any more of an unsafe act than walking downstairs or lighting a fire in the stove. The danger is not in the act but in the way it is performed.

Concentration on elimination of unsafe acts and unsafe conditions will no doubt show results. These results, however, may be temporary. In the period immediately following the reduction of danger, the persons concerned are likely to retain their ability and avoidance skills. Time and employee turnover soon change this situation so the persons concerned may be less likely to be capable of avoiding the danger if it arises. The long term result may therefore be an increase in accidents, or at least a smaller improvement than was originally recognized. This same reduction in "instant hazard awareness" and ability to deal with dangers that may arise may have a broader effect on other dangerous situations. An example of this could be the person who works in a factory where all dangers are eliminated, but who is then let loose in a high powered automobile to drive to his home where equivalent protection does not exist. He has been deluded into the idea that machinery is safe. Similarly, a back injury at work may result from his lack of normal exercise. Elimination of so called "unsafe acts" and "unsafe conditions" although having considerable backing and some basis of truth can be overdone. It is important for the individual as well as the country that each person learn how to cope with his environment, even though some risk must invariably be involved and some injuries result. Let us now look at some of the relationships advanced by Heinrich.

The Foundation and Five Steps to Accident Prevention Fig. 18

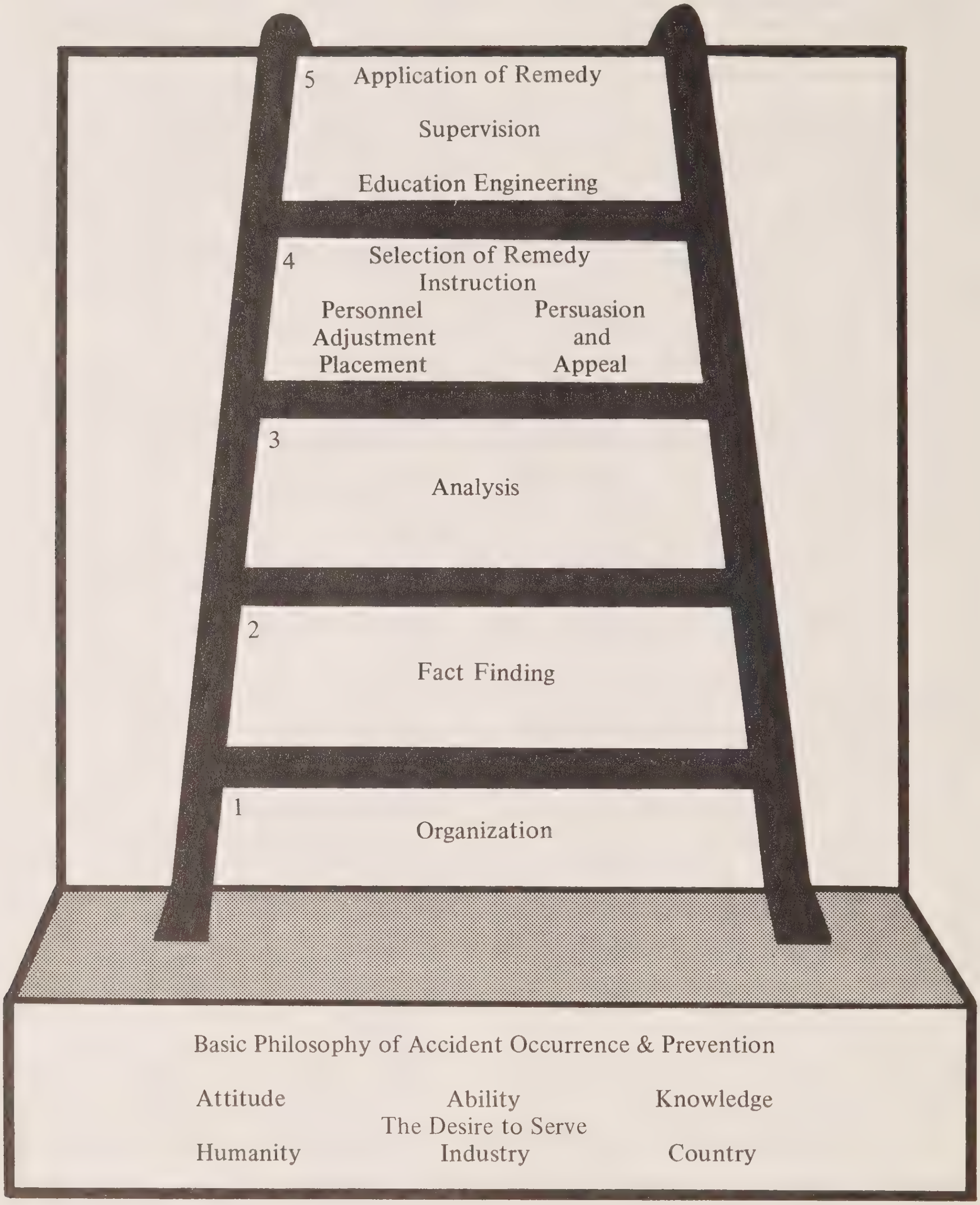
The sequence of the steps in this illustration is sound and should be applied when endeavouring to develop improvements in a safety program. It can be used as a basis for assigning values to the components of loss from accidents and in suggesting improvements.

The error that occurs in the normal application of these 5 steps is most likely to occur in step 4 since the remedy may have a long term or spreading effect that has not been considered or is incapable of estimation. Heinrich does not appear to explain this weakness or even mention that it exists. Use of the relationship L = D.I.C.E. ensures that the effect on awareness resulting from a change in the danger is considered. The suggested weakness of Heinrich's approach is not in the foundation and steps but in their application.

Axioms of Industrial Safety (17)

"1. The occurence of an injury invariably results from a completed sequence of factors — the last one of these being the accident itself. The accident in turn is invariably caused or permitted directly by the unsafe act of a person and/or a mechanical or physical hazard.
2. The unsafe acts of persons are responsible for a majority of accidents.
3. The person who suffers a disabling injury caused by an unsafe act, in the average case has had over 300 narrow escapes from serious injury as a result of committing the very same unsafe act. Likewise, persons are exposed to mechanical hazards hundreds of times before they suffer injury.
4. The severity of an injury is largely fortuitous — the occurrence of the accident that results in injury is largely preventable.
5. The four basic motives or reasons for the occurrence of unsafe acts provide a guide to the selection of appropriate corrective measures.
6. Four basic methods are available for preventing accidents — engineering revision, persuasion and appeal, personnel adjustment, and discipline.
7. Methods of most value in accident prevention are analogous with the methods required for the control of the quality, cost and quantity of production.
8. Management has the best opportunity and ability to initiate the work of prevention, therefore it should assume the responsibility.
9. The supervisor or foreman is the key man in industrial accident prevention. His application of the art of supervision to the control of worker performance is the factor of greatest influence in successful accident prevention. It can be expressed and taught as a simple four-step formula.
10. The humanitarian incentive for preventing accidental injury is supplemented by two powerful economic factors: (1) The safe establishment is efficient and the unsafe establishment is inefficient; (2) the direct employer cost of industrial injuries for compensation claims and for medical

FIG. 18
THE FOUNDATION AND FIVE STEPS TO ACCIDENT PREVENTION: –



Reference – Heinrich Industrial Accident Prevention, 4th Edition, page 10.

treatment is but one-fifth of the total cost which the employer must pay."

Although there is little ground to argue with the axioms as listed (except the ratios quoted) their validity lies in their interpretation, particularly in reference to what constitutes an unsafe act. As previously explained, everything we do can, by some, be described as unsafe. In accident prevention we are replacing one unsafe act or condition with one that will result in accidents of reduced frequency or severity. Improvement cannot be measured having regard only for the situation that was improved but by the short and long term effect on the total accident experience of the individual, work unit, company, community or nation.

The Accident Sequence

Heinrich emphasizes that "a preventable accident is one of five factors in a sequence that results in an injury". (Fig. 19). The sequence is no doubt applicable in most cases and if properly understood can, as in the case of the "foundation and five steps to accident prevention" be useful in calculating causal, prevention and avoidance factors, both before and after a change in a program. Heinrich's concentration on the removal of "unsafe acts" and "mechanical or physical hazards" (unsafe conditions) is a useful example, but in a long term program is incomplete as explained earlier since the hazard can rarely be permanently eliminated and the removal of the hazard may have an adverse effect on a person's ability to deal with unsafe conditions or unsafe acts created by other persons. In utilizing dominoes or similar blocks to illustrate his point he does not draw attention to the fact that forces may act to topple these blocks to the left as well as the right. In removing block No. 3 he is not only removing a causal link but a prevention link as well. Since complete removal of block No. 3 is impossible we must, to be effective, shorten its height so the remaining portion will not strike block No. 4. There is an intermediate point where block 3 will still strike block 4 with greater impact than if the block were whole but this may be beneficial if the blocks are falling in the direction of safety.

If block 4 is reduced in width rather than height it will still strike the adjacent block but with reduced force. The question one must ask here is whether placing block 3 on a diet will make it less visible to block 4 thereby preventing block 4 from acting in time to stop it from falling or forcing it to reverse its direction thereby preventing injury and reducing the probability of a recurrence. It might also be noted that the use of the 5 blocks would indicate that blocks 4 and 5 will be knocked down every time block 3 falls in their direction. This is inconsistent with the view that an accident does not result every time an unsafe act is committed or that the severity of the accident is a matter of chance. Conversely, it indicates that whether an accident occurs (and the severity of the result) is directly related to the force applied by block 3 and inversely related to the stability of blocks 4 and 5. Similarly, the effect of an accident or close call in reducing the probability and severity of future accidents would be related to the impact it has on the person and whether it is sufficient to alter his attitude, actions, etc.

Heinrich speaks of the importance of analyzing the "Minor Injuries" and "No Injury Accidents". (Fig. 20). His argument is that elimination of unsafe acts and conditions associated with minor accidents will prevent major accidents, whereas taking action based solely on information gained in major accidents is often ineffective since the same combination of circumstances may not arise again. It should be noted, however, that similar situations may result in major accidents of other types.

This argument assumes that all minor accidents could have been major accidents and that the minor accidents must, therefore, be kept at a minimum if not eliminated completely. I believe this reasoning to be sound only for accidents where there is a reasonable probability that the same act or condition will result in a major accident. A consideration of reward and risk is important here since risk cannot be eliminated completely and we reach a point where the additional effort to achieve improvement is economically unsound. In addition, the reduction in "instant hazard awareness" associated with removal of dangers that are unlikely to result in major accidents may be detrimental to the overall program, particularly if off the job accidents and long range objectives are considered.

In summary, Heinrich's points are valid if reserved for unsafe acts and unsafe conditions that can be reduced or eliminated without decreasing a person's ability to attend to dangerous situations that remain or that have been created by the reduction in unsafe acts or unsafe conditions.

Where long range goals and interaction factors are considered Heinrich's points are still valid, but must be approached with caution and only with the assistance of persons with experience in human factors and the behavioural sciences to ensure that the long range and interaction effects are worth the temporary gain or if they can be tempered by such methods as special training and artificially added techniques of maintaining attention and hazard recognition.

Motivation Qualities to be Considered in Accident Prevention (Fig. 21)

It appears that the ten commandments and the fact that we have ten toes and ten fingers is the prime reason that most lists contain ten items. There are others that could be added to this list such as the basic drives of hunger, thirst, shelter and sex. Each of these, depending on its current importance in the heirarchical list, may affect the ten items listed. Similarly the list could, by some, be considered as secondary drives or sub-goals to the basic drives. The list itself is not so important as the recognition that for each hazard situation each person may react differently and an individual cannot be expected to react in the same way at all times. Health, environment, time of day, and many other factors will determine his reaction to a given event at a specified time.

Heinrich's most significatn quote (Heinrich Page 181) is an article by E.E. Free written in 1930, advocating the use of psychologists in safety. It is astounding that thirty eight years later the safety movement in Canada is only beginning to recognize the importance of this advice.

**FIG. 19
THE
ACCIDENT
SEQUENCE**

(Heinrich)

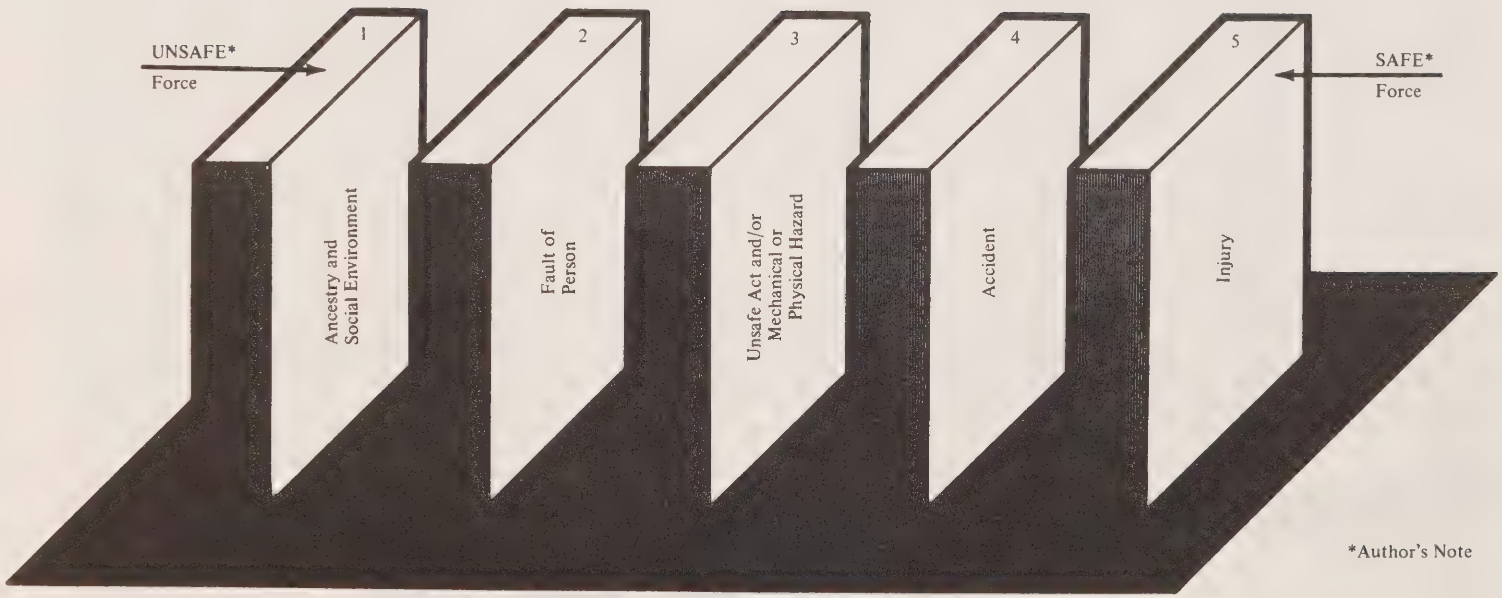


FIG. 20

THE FOUNDATION OF A MAJOR INJURY (Heinrich)

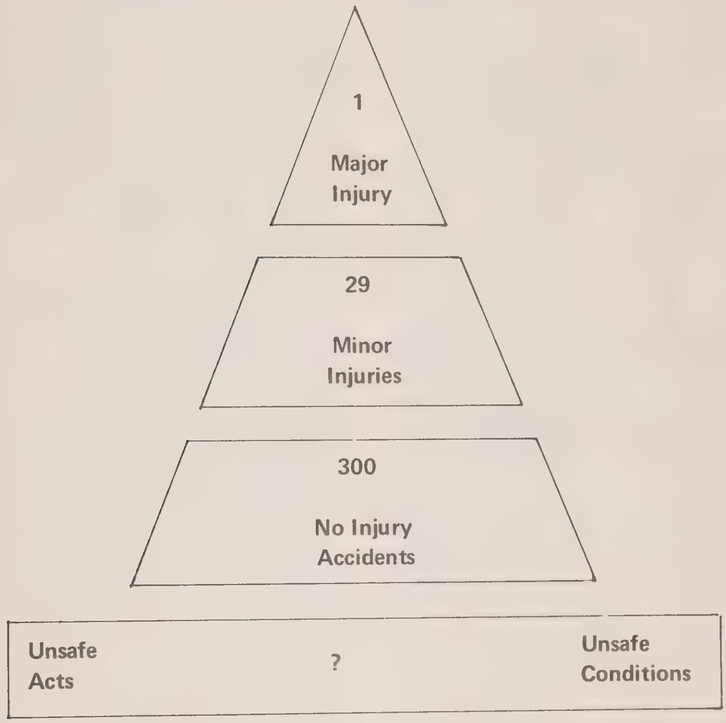


FIG. 21

MOTIVATION QUALITIES TO BE CONSIDERED IN ACCIDENT PREVENTION

(Heinrich – page 148)

1. Self Preservation
2. Personal and material gain
3. Loyalty
4. Responsibility
5. Pride
6. Conformity
7. Rivalry
8. Leadership
9. Logic
10. Humanity

Discussion of Accident Examples (Heinrich — Case 1, page 32)

"An employee, in going to and from work, took a short cut that obliged him to climb a fence and cross a railroad siding that was a part of the plant premises. Cars spotted at this point frequently prevented a clear vision of the tracks, and the noise of the plant machinery (24 hour operation) made it difficult to hear warning whistles and bells. One day, at noon, this man stepped from behind a freight car directly into the path of an oncoming engine, was struck and badly injured. Crossing the tracks at this point was forbidden and notices to that effect were posted. A fence was provided. Trainmen used whistles and bells. In short, the situation was normal, except for non-enforcement of instructions. The employee admitted that he had crossed the tracks four times a day for two and one-half years — or approximately three thousand times prior to his injury — and that he had stumbled, fallen, had to jump hurriedly aside, and otherwise had narrowly escaped injury approximately five hundred times. His first-aid record for the period showed 38 cuts and abrasions sustained while climbing the fence and stumbling over the tracks. The ratio was estimated to be 500-38-1."

Comments:— Without knowledge of clearances, train speed, time saving of shortcut, dangers of preferred route, etc. it is impossible to determine whether or not "crossing the track" was, in itself, an "unsafe act". Since no remedial action was taken until a serious injury occurred it is possible that it was the injury that convinced the employee of the danger. It is also possible that his inattention was caused by haste which was fostered by fear of being late and desire to spend as much time as possible at home. Many other possibilities could be advanced to indicate that until the serious accident occurred, forcing the employee to take the safer route without changing the underlying causes could have resulted in a more serious injury sooner. e.g. He may have walked in front of an automobile. This might be compared to a conciliation officer attempting to mediate a dispute before the parties are ready to negotiate. In such cases his attempts are not only fruitless but may be detrimental to later proceedings. Applying our relationship L = D.I.C.E. to the situation, the potentially dangerous situation is crossing the tracks. If we relate our probability to each crossing D = 1. We would expect L to equal unity if an accident occurred in each crossing. The probability that it will result in injury if unchecked $= I = \frac{500}{3{,}000}$ assuming that the number of close calls is the total number of situations that will result in injury if unchecked. "C" is assumed to equal unity. Measured probability of minor injury $= \frac{38}{3{,}000}$ The probability that nothing effective was done to prevent an accident when an unsafe act was committed in a dangerous situation $= E = \frac{L}{D.\,I.\,C.} = \frac{38 \times 3{,}000}{3{,}000 \times 500 \times 1} = .076$ OR the probability that he will be successful in avoiding injury of any kind = 1 — .076 = 92.4%. It should be noted that this refers only to those situations where he prevented an accident through his own action after he had already committed an unsafe act that would result in injury if unchecked. It does not include the times he crossed the track safely which amounted to $\frac{2{,}962}{3{,}000} = 98.7\%$ of the crossings. If we knew the train's schedule or the number of times he was inattentive when crossing the tracks we could make a more accurate estimate of the potential danger, but his ability to avoid dangers that are present is sufficient for this example.

Following the more serious accident it might be assumed that in the victim's mind this accident is one hundred times as serious as the minor accidents. After all, he might have been killed, whereas the other 38 were mere scratches ("C" for this accident is 100). We now have $E = \frac{L}{D.I.C.}$ where L = 38 + 100. $\therefore E = \frac{138}{3{,}000} \times \frac{3{,}000}{500} = .276$, and his assessment of his ability to avoid is 72.4%.

Prior to the major accident the victim could consider the reward to justify the risk (frequency and severity of punishment), but now the probability of reward has shrunk noticeably and the probability that he will not be able to correct an unsafe condition that he has created by his unsafe act has increased from 7.6% to 27.6%, or almost four times. This may be more effective in determining his decision to change routes than any admonition from management. If left to his own volition, he could either take the new route or develop a safer way to cross the tracks. He is also likely to be more receptive to the suggestion that he use the safer route than he would have been prior to the major accident.

"Industrial Safety by Blake"[3]

Of the accident prevention texts referred to in the Bibliography this appears to come the closest to breaking with the "unsafe act" — "unsafe condition" fixation. His inclusion of "behavioristic cause" as one of fourteen suggested causal factors (page 63) is more fully explained in table ten of his text, under the heading of "Behaviouristic causes of Accidents, How to Eliminate Them, and Functional Responsibility for Corrective Action". He recognizes in this table, human factors related to lack of knowledge and physical defects. Unfortunately, he appears to stop at the point of recognizing human factors that result in performance below that expected of a normal, experienced person. He does not attempt to project the human factors approach into the positive realm of improving a person's ability to cope with dangers that cannot be eliminated. Although some of his examples appear to touch on this subject, he does not seem to have recognized that since deficiencies in human factors can complement or substitute for a reduction in so called unsafe conditions, many unsafe conditions can, in effect, be eliminated by improving a person's ability to the extent that the condition is no longer unsafe. e.g. Training a child to climb stairs eliminates the need for a gate.

Analyzing Hazards Utilizing L = D.I.C.E.

If the loss from an accident could be expressed in a form such as L = D.I.C.E. it would make it possible to determine how

improvement in one aspect of the problem could affect the result while ensuring that the effect on other variables is not ignored.

Let us now see how such a relationship might be used to help understand how the resulting frequency or severity of accidents might be affected by a change in one or more components of the accident situation. It is stressed that the relationship as suggested here may be incomplete and is used for illustrative purposes only at this time to emphasize how such relationships could be used in the accident prevention movement.

If L_1 = Loss due to accidents for an existing program
and L_2 = Loss due to accidents for a proposed program
the savings resulting from the new program can be expressed as $L_1 - L_2$. Also, the relationship between the losses could be expressed as $\frac{L_2}{L_1}$. This could also be written as $\frac{(D._2 I._2 C._2 E._2)}{D._1 I._1 C._1 E._1}$

D_2, I_2, C_2 and E_2 can each be expressed as a fraction or or multiple of D_1, I_1, C_1 and E_1.

Similarly, where multiple hazards are present all possibilities must be summed and it is easy to recognize that where more than one hazard requiring attention occurs simultaneously, "E" will be adversely affected. If any of the values in the numerator can be reduced without increasing another to a greater extent, then a net improvement in the program will result. The conventional approach to accident prevention assumes that this is always the case and ignores the possibility that an improvement in one variable may alter others to such an extent that an adverse result is obtained. If two or more dangerous situations could occur simultaneously, a practical application of this relationship is to emphasize that the decrease in a person's ability to cope with multiple dangers may be greater than any improvement that could be made in reducing individual hazards. It emphasizes the importance of ensuring that two or more dangers cannot occur simultaneously or of arranging a method whereby the additional dangers become the responsibility of another person or can be delayed for attention at a more appropriate time. e.g. — In sailing where the skipper cannot handle the tiller, main and jib sheets simultaneously and they require adjustment with changing wind velocity, bearing, etc. it is necessary to delegate responsibility to the crew although in a light, steady breeze the skipper through the use of various types of fastening mechanism could sail the boat himself. In a heavy or changing wind he would, however, be in serious difficulty.

Many people place themselves in a similar position by endeavouring to handle too many items personally without a second line of defence. Proper delegation of authority therefore is essential to any safety program. An example of this could be an angry driver vs a normal driver. Let us look at a hypothetical example.

Sample Use of Basic Relationship

(Utilizing Hypothetical Figures)

L = (cost of accidents/mile)
D = (potential dangers/mile)
I = (frequency at which the dangers will culminate in an accident if unchecked)
C = (Cost of an individual accident)
E = $1 - A = 1 - a.d_1\ d_2\ d_3\ e_1\ e_2$ = (no effective action will be taken to prevent the accident)
a = (awareness)
d_1 = (correct hazard assessment)
d_2 = (plan formulated)
d_3 = (plan adequate)
e_1 = (attempt to implement)
e_2 = (ability to implement)
L = D.I.C.E.

Situation No.1

Careful driver, normal conditions of driving and psychological state.

D. = 4(1 danger each ¼ mile)
I. = 1
C. = 1 (average accident)
$a = d_1 = d_2 = d_3 = e_1 = e_2 = 1$ (fully capable of attending to all single dangers)
$\therefore\ L = 4 \times 1 \times (1 - 1) = 0.$

If multiple dangers occur in a ratio of 1 for every 1,000 single dangers and the individual is capable of attending to and dealing with 99% of these multiple dangers:

$\therefore\ D_2 = \frac{1}{1{,}000},\quad I_2 = I_1\quad a = e_2 = .99\quad d_1 = d_2 = d_3 = e_1 = 1$

$E_2 = 1 - .99^2 = .02.$

$L_2 = \frac{4}{1{,}000} \times I \times \frac{2}{100} = 1$ average accident for each 12,500 miles. Also, there is approximately 1 fatal accident for every 300 non-fatal accidents. (From National Safety Council).

$\therefore$ a fatal accident would be expected every 12,500 x 300 = 3,750,000 miles.

Situation No. 2

The same driver after an argument releases adrenaline into his system and his system prepares to fight or run. In an automobile, he cannot do either and must substitute something to dissipate the tensions created. If he vents his feelings in loud words or stops and goes for a walk, his susceptibility to accident is not likely to increase appreciably but if he increases the rate of input sensations appropriate to his psychological and physiological condition, he may reach a point where there is no reserve awareness or ability to cope with unplanned multiple dangers. It is similar to attempting to accelerate a car which is already operating at maximum speed.

Assume that his increased action doubles the potential hazards, each of which he can cope with if occuring singly.

$\therefore\ D = 4 \times 2 = 8$

also, an accident if occurring will likely be more severe, so we can assume

C = 2 i.e. The severity is assumed to be doubled.

Also, his full attention and ability are taken in coping with the

situations he is creating. If he is now capable of recognizing only 75% of the multiple dangers then "a" = .75. Similarly, if he has no reserve to cope with the multiple danger e_2 would have a value of zero. We will assume, however, that he can deal with 25% of such situations ∴ $e_2 = .25$. All other factors will be considered as unchanged.

For single danaers $L = 8 \times 2 \times (1 - 1) = 0$

For multiple dangers $L = \frac{8}{1,000} \times 2 \times (1 - 3/4 \times 1 \times 1 \times 1 \times 1 \times ¼) = \frac{13}{1,000}$ or, 13 accidents for each 1,000 miles and 1 fatality for each 23,000 miles.

Note: – using our HYPOTHETICAL FIGURES, anger would increase accident loss by 162 times. If realistic values could be found for the variables we could see the effect of anger on insurance premiums.

Situation No. 3

Using the same figures, if a person were angry 10% of the time his accident costs for each 1,000 miles would be:—

when not angry $.9 \times \frac{1}{12.5} = .075$

and when angry $.1 \times 13 = 1.3$

for the equivalent of 1.375 average accidents for each 1,000 miles *or* more than 17 times the cost for a person who does not drive when angry or who finds safer ways to vent his anger.

The foregoing calculations indicate that the development of mathematical relationships in safety could help place accident prevention in a position where predictions could be made with some reliability, such relationships would also assist in testing the validity of existing theories and practices.

Job Safety Analysis

Whether it be desired to analyze a specific operation or a complete safety program the same operations must be completed. The prime difference being that a complete safety program is the summation of its components. The complexity of the analysis also depends on whether a proposed change will have an adverse or beneficial effect on other operations or hazards and whether such change is worthy of consideration. For this reason we have suggested that a factor to cover the interaction effect should be included in any analysis.

The first operation in assessing hazards is to complete a "Job Breakdown Sheet" (Fig. 22) for each operation. The purpose of this is to assist in recognizing hazards associated with each step of an operation. This is reasonably standard procedure found in several texts. I have based my sheet on one found in "Industrial Safety" by Blake(3) and have added a column for "frequency of hazard" which is necessary for the next step in the survey. When Job Breakdown Sheets have been completed for each operation it is necessary to analyze each hazard and assess its potential importance. This is done using the "Hazard Analysis Worksheet" (Fig. 23). This sheet contains a column for the existing program and another for the new program. Comparing calculated values of L for the existing program and the new program permits evaluation of the net gain to be expected if improvements are implemented.

The column for "improvements" indicates what can be done to each component of L and what resulting change in that component could be expected if there were no interaction effect. Assigning a value to the interaction effect is the most difficult but is extremely important since it may reflect serious long term effects that would nullify early gains resulting from the supposed improvements. e.g. Reducing the frequency of a hazard may reduce accidents to existing personnel who are capable of dealing with hazards that remain, but the same improvement may result in new personnel being unaware of the danger or incapable of coping with it. Since it has not been eliminated completely, it may result in an increased accident frequency to such newer personnel if a suitable training program is not implemented. The adjusted value is determined by multiplying the value calculated for "improvements" by the "interaction effect". The values obtained from the "Hazard Analysis Work Sheet" could be utilized directly in a computer program or transferred to a "Hazard Analysis Summary Sheet" (Fig. 24) for manual calculations. In either case the values for "Existing Program" and "New Program" are summed separately.

Fault Tree Analysis

An alternate method of achieving the same result is the "fault tree" analysis (Mearns)(26). This method has been gaining prominence in the United States, particularly in aerospace industries since 1965 and presents a visual picture of events that must coincide for an accident to occur. If, for example, we had two possible loss producing accident situations resulting in losses per million units of production equal to L_1 and L_2 or $(D_1I_1C_1E_1)$ and $(D_2I_2C_2E_2)$. In Fault Tree Analysis this would be shown as a tree with "and" gates and "or" gates. The "and" gate signifies events that must occur simultaneously and the probability of each component is multiplied. The "or" gate signifies a choice in which case the component probabilities are added. The above noted situation is shown in Fig. 25.

The fault tree analysis has many advantages and is fully compatible with our suggested relationships. Examples quoted indicate it is intended primarily to compute probability of error in a complex electronic system. The fault tree becomes extremely complex when many possible failure situations are present and must eventually be reduced to an algebraic formula for processing. It therefore becomes a matter of preference whether a person uses a fault tree to help understand a series of job safety analyses or to work with the job breakdown sheets for direct insertion in an algebraic formula. Ability to picture all relationships is the deciding factor in determining the method to be used.

Lifting

Perhaps one of the first attempts to apply engineering to the human component of a system in occupational safety was in the field of back injuries. The attempt centred around two basic assumptions:

1. Man was originally designed to walk on four legs.
2. A column will support a greater load when used as a column than when used as a cantilevered beam.

FIG. 22

JOB BREAKDOWN SHEET

FROM BLAKE – page 84)
(Modified)

LOCATION . . . .

PART . . . . OPERATION . . . .

STEPS IN OPERATION	"Key Points" – knacks, hazards "Feel" – timing, special information	Frequency of operation ("D")	Estimated Accident Frequency (I)

FIG. 23

HAZARD ANALYSIS WORK SHEET

(Transfer results to Summary Sheet)

Item #. . . . . Hazard Area . . . .

Hazard Description . . . .

	EXISTING PROGRAM	AFTER IMPROVEMENTS	INTERACTION EFFECT IF APPLICABLE	NEW PROGRAM
"D" dangerous situation				
"I" accident if unchecked				
"C" cost per accident				
"a_1" awareness				
"a_2" assessment of danger				
"a_3" attempt to plan				
"a_4" ability to plan				
"a_5" attempt to implement				
"a_6" ability to implement				
$A=a_1a_2a_3a_4a_5a_6$				
L=D.I.C.E.				

NOTES: — (include description of Machine, controls, surroundings, operator and any other applicable factors).

NOTE: — On final copies include pertinent human factors data on rear, e.g. Reaction Time.

HAZARD ANALYSIS SUMMARY SHEET

Note: This may be completed for "Existing Situation" or "Revised Situation". If it is for the revised situation use "Adjusted Values" from Hazard Analysis Work Sheet. (New Program)

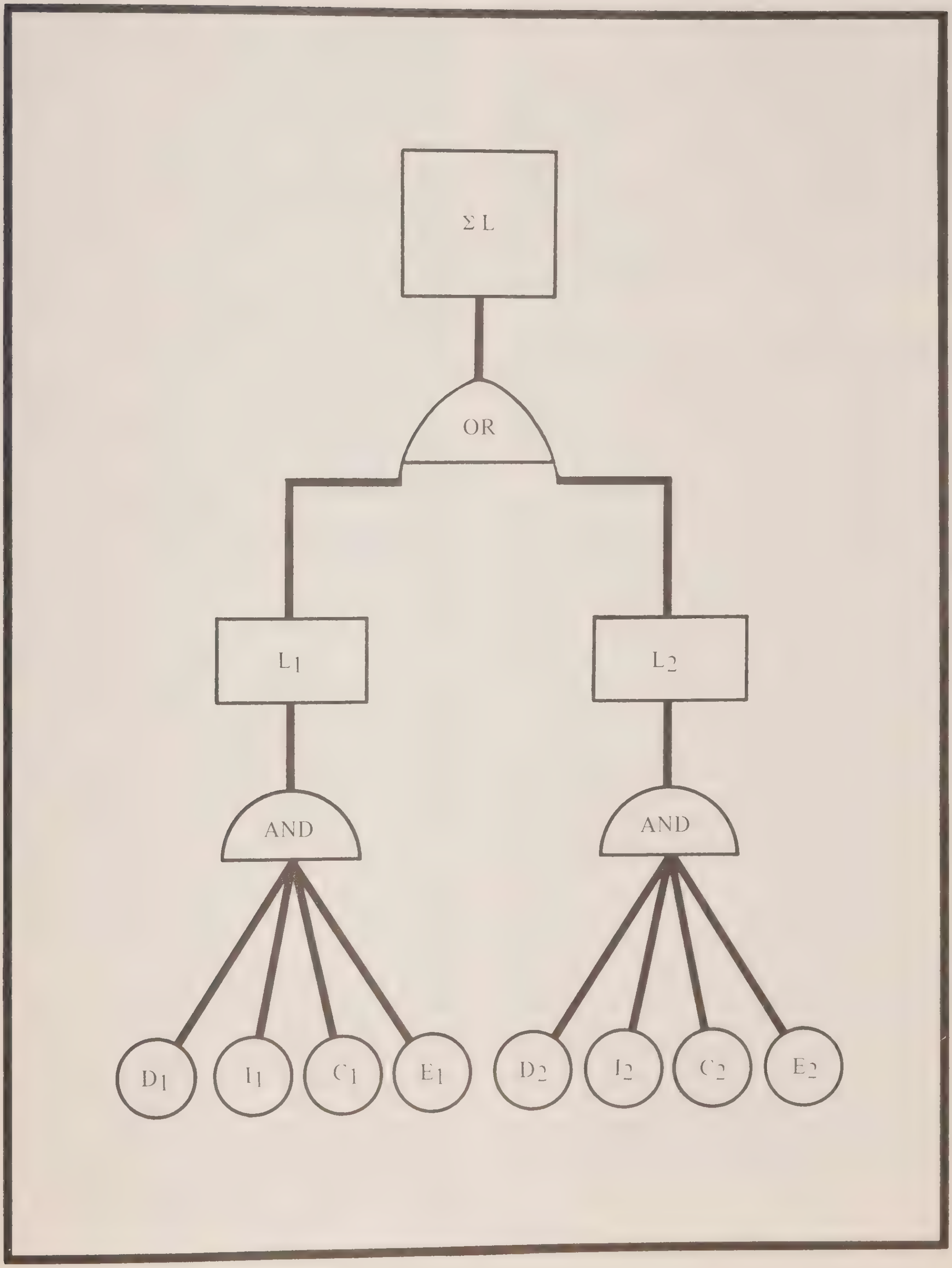
COMPANY . . . .

DATE . . . . EXISTING OR NEW PROGRAM . . . .

PREPARED BY. . . . .

ITEM	HAZARD AREA	TECHNICAL FACTORS				HUMAN FACTORS								
		D	I	C	D.I.C.	a_1	a_2	a_3	a_4	a_5	a_6	A	E	L=D.I.C.E.

FIG. 25



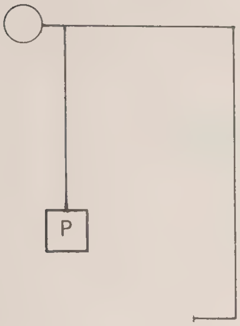
Although the first assumption may be argued by some theologians, not even engineers would likely question the second. If, however, we confront the engineer with the possibility that the column may be composed of materials of varying strengths he would be a little more hesitant in his answer. The human trunk cannot be passed off as a simple homogeneous column. It is an intricate mechanism composed of not only the vertebrae and discs in the spinal column, but of everything enclosed within the skin. If we present the engineer with a composite column shaped like an "H" in which one flange could withstand both tension and compression stresses, the web could withstand only shear stress and the other flange could support tensile stress only, its strength as a column would be greatly reduced whereas it could support comparatively heavy loads if used as a tension member or as a cantilever beam. (The beam would have as the top flange the one which would not support compression stress.) Although this is not an accurate description of the human body, it is much closer than the simple crane normally described in safety literature.

Let us now look at how the attempt at human engineering to prevent lifting injuries has been improperly applied. We will ignore the fact that exercise is necessary to create and maintain the strength and tone of muscles, discs and vertebrae and look only at the mechanical features. We will in effect assume that we are not interested in what a person can lift, but in a comparison of lifting abilities in different positions.

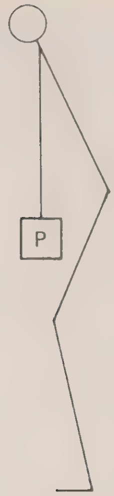
The method of lifting which is normally discouraged (Fig. 26(a)) involves straight legs and back, bending only at the waist. Most people would find it impossible to reach the floor in this manner. If they could, they would be applying the principle of a straight back. Advocates of this principle could indicate that removal of luggage from the trunk of a car should be achieved utilizing this position. Another odd interpretation that has come to my attention is that the knees bent, back straight position should always be used since this prevents you from lifting any object which could strain your back. This is an admission that the legs are not very strong and operate at a tremendous lever disadvantage. This, in turn, may be the reason for the strong leg muscles. Many cannot reach the floor with their knees straight even when bending their back so it is unlikely that Fig. 26(a) would apply to anyone lifting an object from floor level. Table 11-83 of the Human Engineering Guide indicates, that the 50th percentile of male Air Force personnel can exert a lifting force of 520 pounds on a bar 28" above the floor when using the legs straight, waist bent method of lifting. The same table indicates a lifting force of 1,480 pounds when the back is erect and legs are bent (Fig. 26(b)). This would appear to coincide with the long favoured concept that lifting must be done with the legs while holding the back as vertical as possible. The force exerted in the leg bent position in this case was almost three times the force applied in the back lift situation. A further look at our illustrations indicates that this applies only to objects 28" above the floor where the leg would be in a position resulting in a change of approximately 20° in the angle between the upper and lower portions of the legs (at the knee) to move the load 1".

In Fig. 26(c) a vertical load displacement of 1" would be achieved by a knee angle change more closely approximating 2° depending on the subject's arm length, muscular development, etc. (i.e. how sharply his leg would bend at the knee). This would reduce the load by a factor of ten. If the 1,480 pound lift in Fig. 26(b) was limited by the strength of the leg muscles and assuming the 10:1 ratio, the same force in the leg muscles would permit a maximum lift of 148 pounds using the knee lift shown in Fig. 26(c). This is also an impossible position for lifting a bulky load. Since a person must bend his back to reach the floor with knees straight or partially bent, lifting posture as shown in Fig. 26(d) appears to be the type that is most likely used but which has not been recommended. If we examine this figure we note that the load and centre of mass of the body are so located that over-balancing is not a factor, thereby reducing the stress on foot muscles. This would likely reduce the stress on other muscles as well. The spine in this position closely approximates a cable supported on a series of pulleys, the pulleys being the internal organs and muscles. If the upper body including the spine are held in a set relationship (curvature constant) lifting with the legs places a relatively light load on the spinal column. It is obvious from the diagrams that the stress on the spine is less than that in Fig. 26(a). The load that can be lifted in this position is, therefore, greater than "a" and probably less than "b" but it is also possible that it would exceed "b" In any case, when a load is to be lifted from the floor the natural lift shown in "d" will permit a greater lift safely than the leg lift recommended in most safety literature. Although this applies to lifts where the curvature of the body can be maintained, it is obvious that the body must at some stage pass through a position similar to that shown in "a" The transition from "d" to "b" in a lift from floor to waist height is achieved by relying on the object's momentum when approaching the critical stage shown in "a" The curvature of the body can be changed while quickly flexing the legs and bringing the load closer to the body. In fact, the body curvature may not be altered appreciably when shifting from "d" to "b" This transition is illustrated in Figs. 26(e) and 26(f). Such a practice may not be advisable for extremely heavy loads where assistance in lifting should be obtained, but engineering principles would indicate that it is to be preferred over the previously recommended method. It could be argued from this that the easiest or most comfortable method of lifting is best. The method of lifting suggested here is similar to an automobile climbing an ice covered hill which has some bare spots. The driver will accelerate on the bare pavement but reduce acceleration where the traction is uncertain.

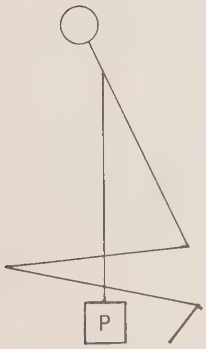
The same principle might account for the phenomenon of back injuries occurring when a person is bending over. If his upper body, head and arms weigh 100 pounds and he bends over to brush his teeth he must apply sufficient force to stop a load of 100 pounds at what may be an icy spot in the road. This force is over and above the force necessary to prevent downward acceleration of the 100 pound load. On the other hand, when straightening up, if he wants to stop his motion he reduces the applied force below that required to maintain the body's velocity. A sudden movement of the body to lean over



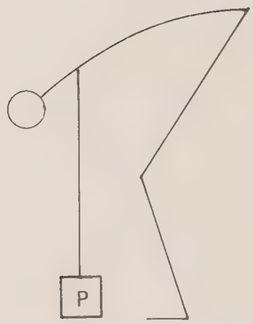
(a)



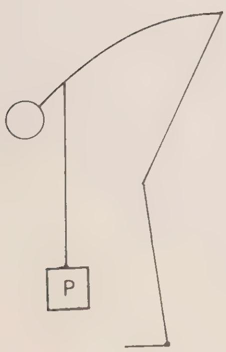
(b)



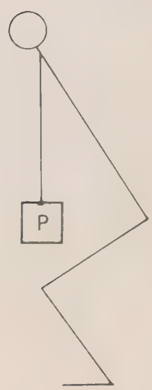
(c)



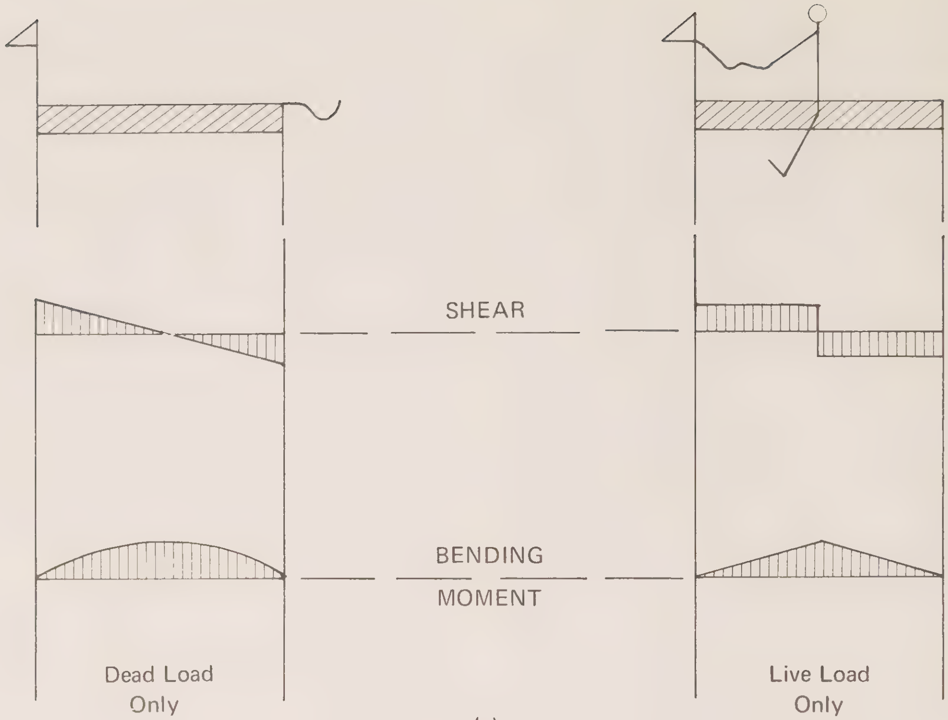
(d)



(e)

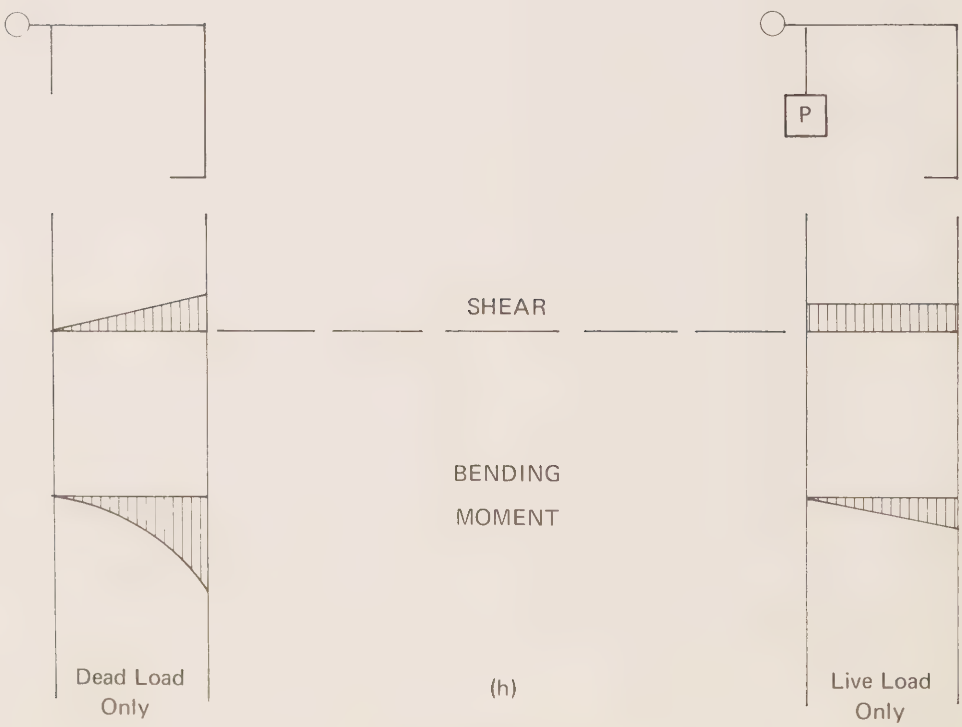


(f)



(g)

Four Legged Animal



Two Legged Animal

the sink (without hand support) may therefore result in deceleration forces equivalent to lifting a sack of potatoes. The foregoing would indicate that the question of back injuries requires a closer look by someone more conversant with human factors than those who developed the lifting postures so widely recommended today.

Now that we have shown cause to question existing methods, let us go back to basic principles and see how they might be of help. The first thing we must determine is the nature of the problem. Since injury to the discs, vertebrae and muscles of the lumbar region of the back (associated with low back pain) appear to be the most common complaint, and as this is the problem which existing concepts attempt to solve, we will focus our attention on this area. It appears unnecessary to go into detail on the importance of aerobic, isometric and calisthenic types of exercises to condition and strengthen the body including the lumbar region of the back since the importance of this is common knowledge. Our task is to determine the lifting position which results in the least stress to the bodily components under consideration. We will look first at the static situation with the load held constant.

Fig. 26(g) shows a four legged animal and a schematic representation of the moments and shear forces that must be resisted due to its own weight and the added weight of a rider. From this it can be seen that although the shear force in the lumbar region is worthy of consideration, the bending moment is negligible.

Fig. 26(h), which shows a man bending at the waist, tells a somewhat different story. It clearly shows that in this position, in addition to resisting the total vertical load (rather than distributing it between front and rear legs as in Fig. 26(g), a substantial bending moment must also be resisted. Utilizing this simple principle we can see that the closer the load is to a vertical line passing through the lumbar region the smaller the moment will become without altering the vertical force. We can also see that if the spinal column is the only part of the organism capable of resisting compression forces the muscles and the spinal column will provide the tensile and compression forces necessary to counteract the moment created by the body weight and the load carried. What we are trying to achieve in our recommended lifting procedures therefore appears to be the creation of a situation where the applied force passes through the lumbar region. Since we are dealing with the dead weight of the body as well as one or more superimposed loads we must expand our thinking and endeavour to have the resultant of these forces pass through the point of origin which in this case is the lumbar region of the back. Only in this way can we eliminate the additional stresses associated with resisting a superimposed bending moment. This must be achieved by positioning the load and the body in such a manner as to bring the resultant of forces as close as possible to the lumbar region. This may involve such procedures as leaning against the load to create a moment equal and opposite to that created by the vertical load or curving the back in a manner so the beneficial effects of moment reduction are greater than the loss in strength created by the curvature.

Let us now project our thoughts to the dynamics of lifting. There is no doubt a greater load can be lifted by bending the legs than by bending the back. Since this is confirmed by scientific investigation, what is not often recognized is the fact that it is due more to the principle of levers than it is to the strength of muscles. When the knee is only partially bent a relatively small muscular force is required to exert a substantial upward thrust. This is similar to the ease in which an object can be moved by application of a lateral force to a rope or cable to which it is attached. If the rope is slack our ability to move the load is greatly reduced as in the case of a knee which is bent at too sharp an angle. This leverage principle also accounts for the reason why it is easier for a person to lift one end of a board than it is for two persons to lift opposite ends simultaneously. This principle of moment reduction and utilization of levers could be expanded further but it is sufficient for the present to emphasize that the previously advocated method of lifting does not fit basic engineering principles in all cases and programs based on this method should therefore be scrapped and replaced with something more realistic. The curvature of the back does not appear as important as the need for maintaining the relative position of adjacent vertebrae while under severe load.

Press Accident Survey

To determine whether the ideas advanced in this paper had practical application, it appeared that study of a specific type of accident would help explain what human factors are present in accident causation, prevention and avoidance, and uncover some common factors that might be useful in a broader study. Accidents involving punch presses occurring in Ontario over the two month period August-September 1967 were selected for this purpose. In several cases the site was visited and responsible company officials were interviewed to act as a check against information received by correspondence. Where practicable the injured worker was also interviewed and in some cases fellow workers. Other presses in the factory were viewed to determine the general adequacy of guarding techniques, apparent ease of operation by the employee, potential dangers and probability that a person could protect himself from dangers that might arise. Detailed notes were not kept for the general conditions in each factory but those factors that appeared relevant were included in the report. The most significant common factor appeared to be that the presses on which accidents occurred operated at sixty or more strokes per

minute. This means that a downstroke was less than .5 seconds. A downstroke of between. 25 and .5 seconds could (depending on the location of controls) permit a person to reach into the die area after tripping the press by hand, but would leave insufficient time to withdraw it again before being trapped. A downstroke of .25 seconds [28] or less would likely be insufficient to permit a person to reach into the die area by reflex type action but, for the same reason, a person would not likely be able to remove his hand in time (if his hand were already in the die area) even if he was signalled that the ram had started to descend. His hand would therefore be trapped. Whether the lack of accidents at slower speeds was due to the operator's ability to protect himself or if it was due to fewer presses operating at the slower speeds, or a reduced probability of failure of such presses, might be shown by a more extensive study. In any case it appears that the only methods of preventing accidents on presses operating at over sixty strokes per minute is to establish a "hands out" policy.

Methods of accomplishing this include automatic equipment, complete enclosure of the die area, tongs, suction tools, magnetic tools, die design and indoctrinating the operator with the idea that since no guard is foolproof he must ensure that no part of his body is ever in the die area except when working on the machine, in which case it shall be stopped and where necessary the ram blocked to prevent its descent. The "hands out" policy is, in some cases, impractical but the objective remains to approach such a policy as closely as possible and to instil in all operators the fact that the machine is dangerous and he has no protection if the machine starts when his hand is in the die area.

Guarding, without suitable indoctrination of danger, appeared to be of little use in some factories visited since the guards, although present were improperly adjusted or otherwise defective and tended to create a false sense of security which, after an accident was replaced by the attitude that since the guards did not protect the employee, accidents are inevitable.

A decision to attempt to reduce loss from accidents in a specific field may be prompted in several ways, including public opinion, intuition and reference to accident statistics. Although a company should investigate all accidents thoroughly, it would appear unreasonable to expect a safety association or Government agency to investigate all accidents. Once it is decided that a problem exists which may warrant corrective action through changes in legislation, enforcement or educational policies, the statistics serve no purpose other than to compare results of the changed program with its predecessor. It should, be remembered that use of such comparisons to prove the validity of a program must be approached with caution, since the change may have been the result of some unknown and uncontrolled factor not included in the supposed improvement. In examining accidents that occurred from August 1st – September 30th 1967, I also enquired about other accidents that previously occurred in the same plant. Some typical cases will be cited.

Case No. 1

This company manufactures metal parts for automobiles. The prime operation involved approximately 12 punch presses of varying size and design. Three accidents involving the loss of fingers or parts thereof occurred within a twelve month period. All machines were provided with guards.

The first accident occurred to a female employee. She had been operating a press requiring the placing of 3" diameter flat discs in the die by hand. She claims that she was adjusting a piece with her finger when the ram descended unexpectedly. Improper adjustment of the pull-back guards fastened to her wrists resulted in an attempt at withdrawal (by the guard) after the finger was caught. The end joint of the finger was pulled off. Close visual attention required at the work place reduced the possibility of the operator receiving any visual warning. This could have been a factor since the press had a downstroke time of less than ½ second but more than ¼ second. A withdrawal reflex in this case could not be relied on to prevent injury even if visual or auditory warning were received at the start of the stroke but it could help. Discussions with the employee indicated that the press (since removed) had on previous occasions operated unexpectedly, but she had through some "sixth sense" withdrawn her hand in time. This is consistent with tests which indicate a reaction time for simple reflexes as varying from .2 to .5 seconds.[28] It fits the "trapped" category perfectly and it could be argued that the guard contributed to the accident since the foreman supposedly checked its adjustment daily and all employees were assured that the guards would protect them. This could have reduced her awareness of danger, thereby preventing most effective utilization of a withdrawal reflex conditioned to the distinctive "clunk" heard when the dog engaged at the start of each stroke. The remedy appears to lie in ensuring that the employees appreciate that the guard is only a second line of defence to supplement their own abilities. They must understand and practice simple methods of safely checking the adjustment of their guard rather than relying entirely on the foreman.

The second accident involved a female employee working on a small blanking operation, removing corners from metal plates approximately 5" x 7" in size. The die area was guarded with a plexiglas plate leaving a slot less than ½" high to receive the stock. Although the pinch point was approximately 3" behind the guard and the opening would not permit entry of my fingers, the employee's fingers being smaller in diameter could (and did) enter the opening sufficiently to permit the die to remove the tip of a finger. The employee was not interviewed personally but it is reported by fellow employees that she had been ill and extremely tired. It is assumed that her reflexes and awareness were at a low level and she fell forward, forcing her fingers under the guard. This would be classed as a "fell" type of accident with the remedy being a reduced opening in the guard having regard for the diameter of the operator's fingers, and ensuring that sick or fatigued workers are not in a position where their reduced awareness and ability could result in injury to themselves or others. It might also be argued that the accident could be placed in the "reached" category, since she knew she could not perform at her normal level. In this case, however, the guard was present and she was assured it would protect her, placing the accident

clearly in the "fell" category.

The third accident involved the foreman who was in charge of the installation and adjustment of all guards. He was adjusting a counting mechanism on a press and placed his hand on a cross bar in an apparently safe location for support. He then instructed the operator to trip the press so he could see if the pressure he was applying manually to the spring on the counter was suitable. A fixed projection on the ram was sufficiently close to the crossbar that it removed the end joint of his finger. This was a "trapped" accident since his attention was focussed on the counter and he had no warning of the injury until it occurred. Although providing a guard to prevent a person from resting on the horizontal bar might be considered, the situation which resulted in the foreman using the bar for support would also have necessitated removal of the guard. It is interesting that such an accident happened to the foreman who was completely responsible for guarding and should have been aware of the danger. It is also of interest that during my visit I noticed a pullback guard that appeared to be improperly adjusted, but which the foreman thought was o.k. until he checked it in my presence and found it to present the same hazard as had resulted in the first accident mentioned. It appeared that the prime cause of accidents in this plant was not so much the quality of guarding as it was the placing of too much responsibility on the foreman, too much reliance on the guards, and insufficient recognition of the ability of the individual employees to understand dangers and utilize their human ability to protect themselves.

Case No.2

This accident involved an employee placing a part in the die area and inadvertently tripping the press. The downstroke was approximately .3 seconds. Although the press was equipped with two hand controls, with palm buttons located 2′ from the pinch point, the operator had switched to foot control. This was done since the parts were of spring material and the finished position in the die made it necessary to remove them with a screwdriver. Hand control would have necessitated putting the screwdriver down and retrieving it for each stroke. It is also possible that the hand controls were awkward for use by the operator who was 5′ 7″ tall. This was the first press accident the company had suffered in over fourteen years. Their operations involve relatively low volume and frequent die changes, making the development of conditioned reflexes of reaching into a die at the wrong time an unlikely possibility. This may account, at least in part, for their good record in the absence of pull-back, sweep, or gate guards. It would be classed as a "trapped" type of accident since he did not intentionally trip the press and there was insufficient warning to ensure reflex withdrawal. Due to the company's otherwise good experience in the absence of more conventional guards, it appears that the die should be re-designed so a tool is not required for removal of the part, *or* so the same tool can be used for both placing and removal.

The second alternative appears preferable since it would also reduce the possibility of "reached" type of accidents, whereby an operator might decide to adjust a part after signalling his foot to trip the press and not be able to cancel the foot motion in time to prevent tripping. Another human engineering fault noticed on all foot treadle operated machines is the design of the protective cover which often makes it inconvenient for the operator to remove his foot from the treadle after each stroke. A re-designed treadle cover with double width to include a foot rest position could be useful along with a treadle designed for sufficient pressure[28] to prevent inadvertent tripping if a person's hand must be in the die area at any time.

Case No. 3

A foreman was adjusting the die in a press which was designed for automatic operation with the die area completely enclosed. The guards were removed for the purpose of adjusting the die and the foreman attempted to "inch" the press to test the alignment of the die. He was holding a part in position with his hand. His hand was caught and a finger amputated when the ram moved further than expected. This was a "reached" type of accident since he actuated the press when he knew his hand was in a dangerous position. The recommended procedure is to shut off the power to the press and block the ram from descending when working on the die, but this is often overlooked by set-up men as evidenced by another similar accident where a foreman admitted that he had been working on dies for years without shutting off the power. I spoke to him in hospital where he was recovering from the effects of four amputated fingers which resulted from his inadvertent tripping of a press when he was working on the die. In both situations a foot treadle was used with a conventional cover guard and the downstroke time was less than ½ second. Both were "reached" type of accidents because the foreman knew the danger and was relying on his own ability too heavily.

Case No. 4

This case involved a female operator with eight years experience and no previous injury. She had never been observed bypassing guards or otherwise interfering with controls. The downstroke of the press took approximately .37 seconds. Two hand controls of the palm button type are located approximately 14″ from the pinch point. It was assumed that the press double tripped (completed two full cycles instead of one before stopping), since the operator did not remember tripping the press a second time. Investigation by the company indicated that there was insufficient wear on the parts to cause the press to double trip. In spite of this they instituted a program of replacing parts at more frequent intervals than suggested by the manufacturer. If the company's assessment is correct, this would be a "trapped" type of accident but other possibilities arise including the possibility that replacing parts at more frequent intervals increases the probability that a faulty part will be used. It is also possible that the operator's development of conditioned reflexes may have been a contributing factor. The following hypothetical sequence of events becomes possible when considering that .37 seconds would permit a trained operator to move her hands from the control buttons to the die area. If it is assumed that she actuated the press, a human engineer or behavioural scientist might suggest:

(1)She had several behaviour patterns (or programs) developed to the point where they could be classed as learned reflexes.

These include:

a. Place part in machine.
b. Press buttons.
c. Remove part.

The sequence is repeated continuously and follows a regular pattern, except when an unforeseen event occurs, in which case the program is disrupted and a sub-routine interjected.

(2)On Receipt of appropriate signals;

(a) The operator's brain emitted a message to actuate the "button pushing program".
(b) Visual stimuli signalled the brain that the part was misplaced, resulting in a new message emitted from the brain to inhibit the button pushing response and adjust the part before proceeding further. (c)
(c) Timing of signals is such that the buttons are tripped before the new signal is received by the muscles.
(d) Tactile and auditory stimuli advise the brain of the unforeseen danger and a new signal is sent to the muscles to cancel the "adjust part" message and implement the withdrawal reflex.
(e) The timing of messages is again insufficient and the hands reach the die area before the ram has reached the bottom of its stroke.
(f) The ram contacts the fingers before the withdrawal reflex can be implemented.
(g) Shock of the injury prevents the sequence of events from being transferred to the operator's long term memory and permits loss of the sequence of events from the short term memory[7].
(h) The operator is convinced that she did not trip the press a second time.

It would appear that the downstroke time of a press should be considered in conjunction with the time it takes an operator's hands to move from the controls to the die area when determining whether two hand controls are a reasonable substitute for other types of guards or personal awareness of danger when attempting to prevent "reached" type of accidents.

A reference to the filter theory advanced by Broadbent[4] appears appropriate at this point (page 34). "It is not impossible to do two things at once. What seems to be impossible . . . . is to handle more than a critical amount of information in a given time. Once the limit is reached, one task fails while the other is still adequately performed". Clearly, if this is correct, it would be expected that a person could show up favourably in a reaction test but be in no state to cope effectively with his environment.

Broadbent also indicates (page 57) "There is a clear advantage biologically in the effect of practice in reducing the capacity devoted to a particular task to the minimum, as this allows the simultaneous performance of other tasks".

The importance of maintaining a reservoir or "factor of safety" when considering awareness and reaction times is also illustrated in Broadbent's comments on vigilance (page 134) ". . . the information striking the sense organs is filtered, and only part of it is passed on to the centres in the brain which organize response. Normally the filter passes that information which is relevant to the task. . . .but occasionally. . . .irrelevant stimuli may be passed by the filter. . . .and during this time task information will not enter". and (page 242) "The Conception is that information is held in a short term store with a very limited time span. From this store it may be passed selectively by a filter through some mechanism of limited capacity from which it is returned to store; this furnishes a method of indefinitely long storage as long as no response to other stimuli is required".

The concepts appear to be consistent with the possibilities advanced for the punch press accident and with other ideas set forth in this paper.

Note:— More recent developments in this area may be found in reference 39.

Conclusions re Press Survey:—

(1)Foot treadle guards should be investigated to determine if a double width guard rather than a single width guard would provide more safety by permitting the operator to move his foot more easily from the treadle and replace it as required. i.e. Rest pedal is equivalent to accelerator and activating treadle is similar to car brake. Sideways foot movement is easier than back and forth.

(2)Hand controls should be placed having regard to speed of downstroke to prevent injury from reflex type reaching into the die area after tripping.

(3)In case of double trip, faster speeds are the worst since withdrawal reflex is impossible, i.e. if an operator has a withdrawal reaction time of .25 seconds he cannot remove his hand in time if the commencement of a downstroke is his first warning and the press has a speed of 120 r.p.m. or 120 strokes/min. With a safety factor of 2 and recognizing that the operator's reflex may take as long as .5 seconds it would be reasonable to assume that if a person's hand must be in the die area at any time, sweep, pullback, or gate guards are necessary for all presses operating at more than 60 r.p.m. At less than 60 strokes/min. guards are not as essential but should be used where possible in the event that the operator is not alert, is distracted, or has not developed a conditioned withdrawal reflex actuated by an audible or other signal coincident with commencement of a downstroke of the ram.

Reaction Time

If we consider an average worker in normal health to have the following minimum and maximum reaction times we can look at the punch press situation to determine what type of accident is likely to occur on presses of various speeds. We will assume that there is no time delay in the controls or operating mechanisms. (See Fig. 27 and 28).

If a person's hand is in the die area and the ram commences its descent unexpectedly we must consider the simple withdrawal reflex triggered by either an auditory or visual signal to prevent him from being "trapped". The best reaction time we might expect is .2 seconds in which case he would be unable to avoid an injury if the press operated at 150 strokes per minute or more. If, however, we considered his maximum reaction time to be .5 seconds he could withdraw his hand safely when

FIG. 27

	Reaction Time (seconds) (Practical Range)	
	Minimum	Maximum
Single Reaction	.20	.40
Double Reaction	.35	.80

FIG. 28

Press Speed r.p.m. (strokes per min.)	150	120	100	86	75	60	50	43	37	33	30
Downstroke Time: Seconds	.20	.25	.30	.35	.40	.50	60	.70	.80	.90	1.0

operating any press at 60 strokes per minute or less. During set-up or other operations requiring more attention to the job and less automatic movements, .5 seconds would likely be inadequate. In such cases 1 second could be more realistic indicating the critical speed to be in the neighbourhood of 30 strokes per minute.

If he commenced to "reach" into the die area after tripping the press this also would be a simple reflex and he could be trapped if the press operated at 150 strokes per minute or less (since .20 seconds is considered critical).

If he receives visual or auditory warning that the ram is descending after commencing to "reach" into the die area he must check the forward movement of his hand and implement a withdrawal reflex. This can be considered a double reflex with minimum and maximum reaction times of .35 and .80 seconds respectively. With reaction time of .35 seconds he could prevent injury on any press operating at 86 strokes per minute or less. With reaction time of .80 seconds the press must be operating at 37 strokes per minute or less.

Putting these results together we can predict that:

(1)"Trapped" type of accidents will most likely occur on presses operating at more than 60 strokes per minute with the person being able to avoid such accidents with decreasing probability up to 150 strokes per minute.

(2)"Reached" type of accidents will most likely occur on presses operating between 37 and 150 strokes per minute with few occurring at more than 150 strokes per minute. Those that occur at less than 37 strokes per minute are likely to be associated with below normal awareness, resulting from a deficiency in the operator or an inadequate warning transmitted by the machine. This would indicate that guarding of punch presses is most important at speeds in excess of 37 strokes per minute. If trapped type of accidents are to be prevented, guarding is most advisable between 37 and 150 strokes per minute with reductions related to type of controls and proximity of the controls to the die. Since the critical press speeds noted above assume no time delay in the controls and that the pinch point is reached at the mid point of the cycle they are inaccurate and should be used as a rough guide only. The pinch point is actually created before the ram reaches the bottom of its stroke, there is delay in the controls and the downstroke time may be more or less than half the time required for a full cycle. This is dependent on many factors including length of stroke, type of controls, driving mechanism (mechanical, air or hydraulic) and die design. The important variable requiring attention is the elapsed time between actuating the tripping mechanism (or presence of a warning stimulus) and the creation of a pinch point. If personal avoidance of injury by human action is 98% effective on a press operating at say 40 strokes per minute and a guard is installed that is also 98% effective (and does not interfere with the operator's awareness, determination and effort at avoidance), it is obvious that a potential of 100 accidents can be reduced to 2 by either method or to .04 by the two methods combined. It would also indicate that installation of the guard is such a manner as to extinguish the human component of avoidance would be no better than relying entirely on the person's own avoidance capabilities. This emphasizes the need of instilling in operators that guards are merely a second line of defence to help compensate for human error and that the guards are also subject to failure.

The foregoing suggestions are arrived at by assuming that published figures for reaction times for simple and complex reflexes are applicable to the operator of a punch press in an industrial application. It is recognized that the figures used may not be directly applicable to this situation but the principle is valid and attempts to improve safety in this area should not be undertaken without first conducting a controlled experiment to properly investigate the contribution of reaction times.

Safety Survey of a Medium Sized Factory

The purpose of this survey was to see if the concepts that were developed in this paper and which appeared to be confirmed by the study of punch press accidents would also form a basis for recommendations to reduce the total accident experience in a factory.

The study reinforced the writer's view that a cursory examination of specific hazards in a factory is not only inadequate but may be dangerous. There appears no doubt that a useful program can only be developed through analysis of the entire operations having regard for the human factors as well as the technical factors. For example; a cursory examination indicated the need for increased use of conveyors to reduce muscular strains. A more detailed examination indicated that contrary to the impression gathered from the accident reports, the strains were the direct result of human engineering faults in the conveyors already in use. This faulty reporting was not an attempt to obscure the facts or sloppy reporting but an accident reporting form which is designed more for compensation purposes than to attempt to uncover the true cause. This raises the question of whether any accident reporting scheme can do more than point the finger in the general direction of a problem so a more detailed study can be conducted both in the field and in the laboratory.

The prime points gleaned from the plant survey that coincided with concepts advanced in this paper are:

1. The most serious hazards, if obvious, tend to result in few, if any accidents.
2. Installations which appear safe may on more detailed examination (including study of accident records) be found to contain hidden hazards resulting in more accidents than from hazards that are more obvious.
3. Concentration on avoiding obvious hazards may result in injury from those which are less obvious, emphasizing the need for good housekeeping and removal of unnecessary dangers to keep the total of remaining hazards at a level with which the occupants can cope effectively.

CHAPTER V

SUMMARY

Summary

In addition to mechanical or material safeguards, human factors can be utilized effectively to reduce the frequency and severity of accidents. In addition, the increased use of mechanical or material safeguards without consideration of the human factors may have a detrimental effect by reducing the availability or effectiveness of human factors in preventing and correcting accident situations. In studying accidents the resulting recommendations may vary depending on whether the cause was classified as "reached", "fell" or "trapped" and whether the most useful remedy is the reduction of danger or the improvement of awareness, determination and effort.

A person exposed to hazards may avoid injury through his ability to cope with his environment or be injured through the lack of such ability. The frequency or severity of the resulting accidents is often determined by whether an unsafe condition is present when the unsafe act occurs. An examination of accidents must include a study of not only the persons injured, but those who were not injured to determine if the fault lies with the condition or the person.

The purpose of accident prevention is to reduce the frequency of accidents and the severity of accidents which occur. This is achieved primarily through engineering, research and education and to a lesser degree through enforcement. Research provides the answers while engineering and education are the media by which knowledge is transmitted to people. In this way unforeseen events can be kept at a minimum and ability to cope with those that remain can be maximized particularly for those which are aversive. A person's decision to proceed with a task and his method of operation are decided in part by his assessment of the rewards of success, the risk of failure and whether he is prepared to accept the consequences of failure. Increasing the frequency of events may decrease the frequency of unforeseen events, *or* conversely, decreasing the frequency of events may increase the probability that they will be unforeseen when they occur.

Humans may cause, prevent or correct potential accident situations. The classical approach is to protect people against themselves (prevent) but this may decrease their ability to correct potential accident situations that may arise. It doesn't attempt to find why some persons cause accidents; if this were known it would permit removal of the cause. The remedy may be to remove the person, train him or change his attitude.

Since a person might be able to cope with individual hazards, but deal less effectively with hazards occurring simultaneously, any study of accident cause or avoidance should take this into account. It would appear that it is important to keep hazards to a limit within which the person can be expected to cope as they occur, or to provide additional persons on immediate call when multiple situations occur,[27] e.g. The County Mutual-Aid Fire Protection System or reserve platoons in an army or standby exhaust units, etc.

Concentrating on removal of hazards as the prime means of reducing occupational injury is inadequate, since it only relates to those situations where a potentially dangerous situation has not been rectified, or, in some cases has been created by human action. It ignores the multitude of cases where correct action has been taken. In analyzing the relationship L = D.I.C.E. it has been seen that a technical factor "D" must be present before an event can be called an accident. It has also been seen that reduction in the "technical factor" may result in a decrease in the "human factor" "E" with a corresponding increase in frequency or severity. In examining accidents we have in the past concentrated on cases where the human factor has been causal or ineffective and tended to attempt correction by removing what we called "unsafe acts" and "unsafe conditions". In doing this we have tended to ignore the far greater number of situations where the "human factor" has prevented or avoided an accident, even though the technical factor has indicated an accident should have occurred. Future investigations, if they are to result in useful recommendations should include an examination of situations similar to that which resulted in the accident, but where an accident was prevented or avoided by human action.

In any study of accidents we must consider causal, prevention and avoidance factors from a human engineering point of view. Causes fall into three basic categories, "reached", "fell" and "trapped" whereas prevention and avoidance require "awareness", "determination" and "effort". Conventional accident coding although useful in locating problem areas and for speech material is of little use in developing useful improvements.

It seems reasonable to recommend that:—

(1) Where the technical factors (unsafe conditions) are improved, means must be found to ensure that the human factors are not adversely affected.

(2) Training should include practice in action to be taken when predictable or unforeseen hazards arise.

(3) It should be emphasized that guards are not infallible and should be considered as a supplement to, rather than a substitute for, human action.

(4) A person should maintain a "plan of retreat" or have a "second line of defence" whenever involved in a dangerous situation or when working close to the limit of his capabilities.

(5) A person should never attempt a complex or difficult task when tired or otherwise not mentally or physically capable of performing the task.

(6) Training and experience can, in many cases, be equally or more effective in reducing accidents than removal of hazards since such removal decreases ability to avoid hazards, and therefore becomes self defeating when carried to extremes.

The safe worker:—

(a) Is proficient in his work

(b) Maintains a pace to assure alertness while keeping a reservoir of attention and ability for his total environment and unforeseen situations.

(c) Plans and maintains an escape route or second line of defence, and,

(d) Tests his abilities including second line of defence and escape routes at appropriate intervals, when danger is not present or is at a minimum.

The unsafe worker:—

(a) Is not proficient in his work, or

(b) Does not maintain a pace that assures alertness compatible

with the task and his abilities (he may work either too slow or too fast), or,

(c) Does not maintain a sufficient reservoir of attention and ability or,

(d) Does not plan or practice second lines of defence and escape routes (avoidance procedures), or,

(e) Tests his abilities, defences and escape routes at inappropriate times, (if at all).

OR in Engineering terms:—

A SAFE WORKER NORMALLY OPERATES WITHIN HIS ELASTICITY RANGE AND EXTENDS INTO HIS PLASTICITY RANGE ONLY WHEN SUCH ACTION WILL BROADEN HIS ELASTICITY RANGE FOR FUTURE USE, WHEN THE PROBABILITY OF INADVERTENTLY EXCEEDING THE PLASTIC LIMIT IS LOW OR WHEN SUCH EXTENSION IS NECESSARY TO REDUCE THE PROBABILITY OR SEVERITY OF ACCIDENT.

(This is compared to elastic vs plastic theory for steel building design.)

Many safety experts are still applying the equivalent of elastic design in not recognizing individual ability and the benefits of plasticity in improving a person's ability to prevent accidents.

Improving a person's ability to take care of himself may be compared to the manufacture of nylon fibres. Initially weak but, under controlled stress in the plastic range, the molecules are reoriented to provide increased strength and ability to withstand heavy loads.

It would appear that the three E's are merely tools in an accident prevention program and that the really important factors are the three C's. Not the time worn "care", "courtesy" and "common sense" but the more basic and realistic "competence", "compatability" and "common sense". Through the intelligent use of human factors engineering and the consideration of the individual as a part of a system or systems we can help ensure that a person and his environment are compatible, increase the probability that he can learn to cope with his environment competently and facilitate his application of commen sense to situations that may arise.

In conclusion, an understanding of Human Factors is essential to any attempt at reducing accidents and their consequences.

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